HYDROLOGIC AND HYDRAULIC ASSESSMENT – SCOUR ANALYSIS

GOODNOW ROAD BRIDGE
BIRCH HILL DAM

ROYALSTON, MASS

SUBMITTED TO:

DEPARTMENT OF THE ARMY
NEW ENGLAND DIVISION, CORPS OF ENGINEERS
424 TRAPELO ROAD
WALTHAM, MASSACHUSETTS

SUBMITTED BY:

HYDRAULIC & WATER RESOURCES ENGINEERS, INC.
1345 Main Street
Waltham, MA 02154

CONTRACT NO. DACW 33 – 92 – D – 0003

SEPTEMBER 1993

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GOODNOW ROAD BRIDGE, BIRCH HILL DAM
ROYALSTON, MASSACHUSETTS

1.0 INTRODUCTION

This report addresses the hydrologic and hydraulic assessment of scour potential under the New England Division, Corps of Engineers Bridge Inspection Program for the Goodnow Road Bridge over Priest Brook in the Birch Hill Dam reservoir area in Royalston, Massachusetts. The scour analysis was performed in accordance with Department of Transportation, Federal Highway Administration (FHWA) procedures. The analysis includes: determination of scour critical flows and velocities, estimation of maximum potential scour depth and recommendation for minimizing or preventing further scour at the bridge.

2.0 PROJECT DESCRIPTION

2.1 Location

The project site is located in the central Massachusetts town of Royalston (see Figure I), between the towns of Warwick and Waterville. Goodnow Road Bridge spans Priest Brook at about 1700 feet upstream from its confluence with Millers River. Priest Brook has a total drainage area of 19.4 mi^2 at gage #01162500 and 23.58 mi^2 to the Goodnow Road Bridge site. The bridge is within the Birch Hill Reservoir area and can be accessed from Old Route 202.

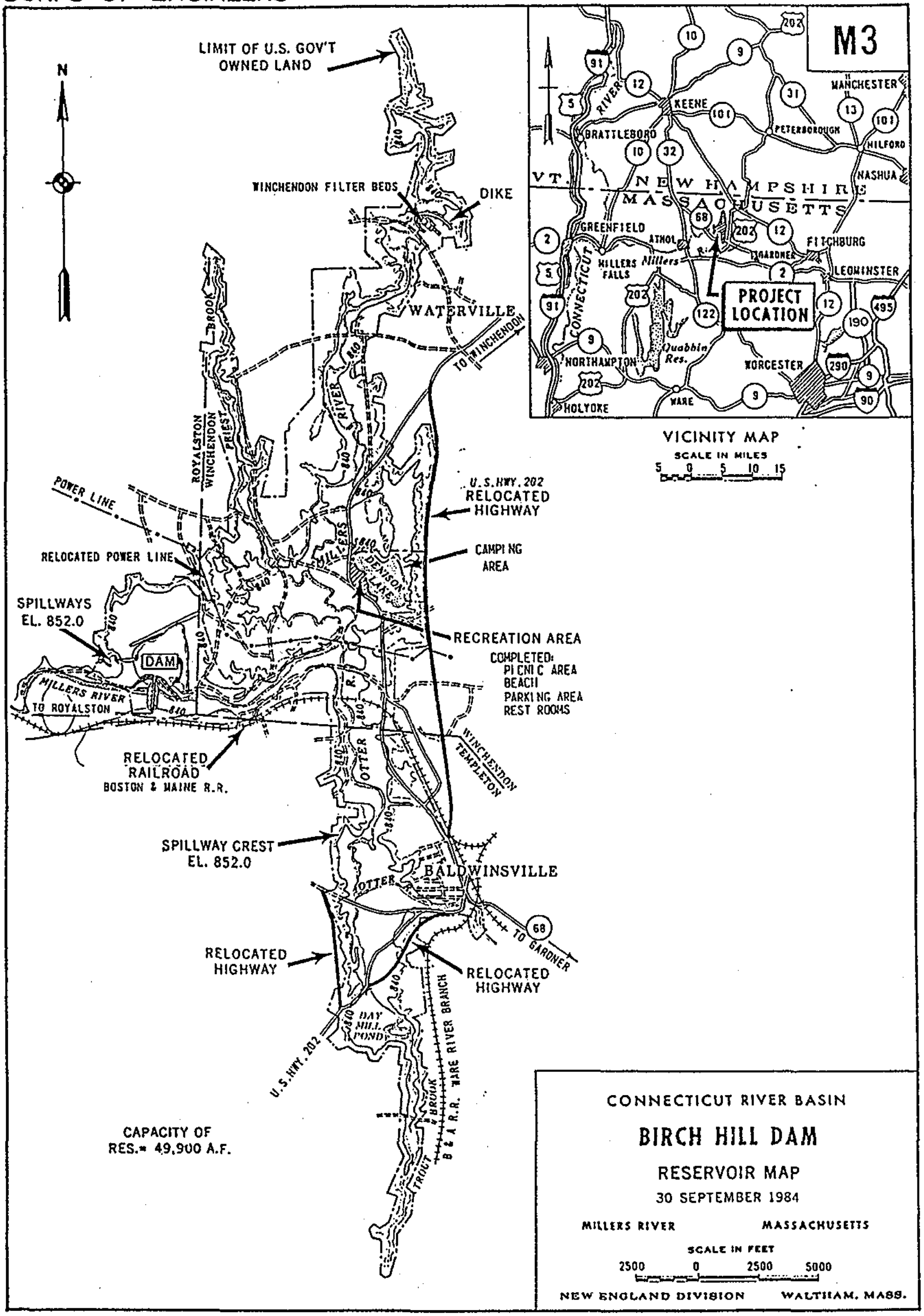

Figure I Locus Map

MAP BASED ON U.S.G.S QUAD. WINCHENDON, MA–N.H. 42072 – F1 – TM – 025 SCALE: 1 : 25,000	HYDRAULIC & WATER RESOURCES ENGRS, INC. CONSULTING ENGRS. WALTHAM, MA 02154
	DEPT OF THE ARMY NEW ENGLAND DIVISION CORPS OF ENGINEERS WALTHAM, MA 02154
	GOODNOW ROAD BRIDGE BRIDGE SCOUR ANALYSIS INDEX MAP

Figure I (continued)

2.2 Site Conditions

Priest Brook runs southerly in its upper watershed, but flows southeasterly through the bridge area towards its confluence with Millers River. The brook slopes at about 3.7 percent near the bridge.

Priest Brook is slightly meandering with its banks covered by medium to dense vegetation. Materials on the streambed consist of sand, gravel, cobbles and boulders. The mean diameter was estimated to be from 1.0 - 1.5 feet by visual observation (May 17, 1993). The Corps of Engineers recently conducted a gradation analysis of sand and gravel matrix which exists between cobbles and boulders (Geotechnical Assessment for Bridge Scour Study, August, 1993). The analysis showed that the mean diameter, D_{50}, by weight for sand and gravel matrix is about 1.5 millimeters (mm). In the upper reaches of the brook, the land is fairly flat on both sides of the channel. In the lower reaches beyond the bridge, it is similar but has a much flatter overbank area (See Photos #1 to 4). Photos #5 and 6 show the stream and streambed material in the vicinity of the bridge.

Figure II is a schematic showing alignment of the bridge and locations of cross-sections for hydraulic analysis. Plan and vertical views of the bridge are shown in Figures III and IV. At normal and lower discharges, such as that seen during our site visit, the bridge does not appear to restrict the flow because the bridge abutments are set close to the edges of the main channel. At higher discharges,

Photo # 1: Goodnow Road Bridge, View from Upstream

Photo # 2: Goodnow Road Bridge, Upstream Embankment

Photo # 3: Goodnow Road Bridge, Looking Downstream

Photo # 4: Goodnow Road Bridge, Downstream Overbank

Photo # 5: Goodnow Road Bridge, Downstream Face of Bridge

Photo # 6: Goodnow Road Bridge, View of Bed Material

GOODNOW RD. BRIDGE

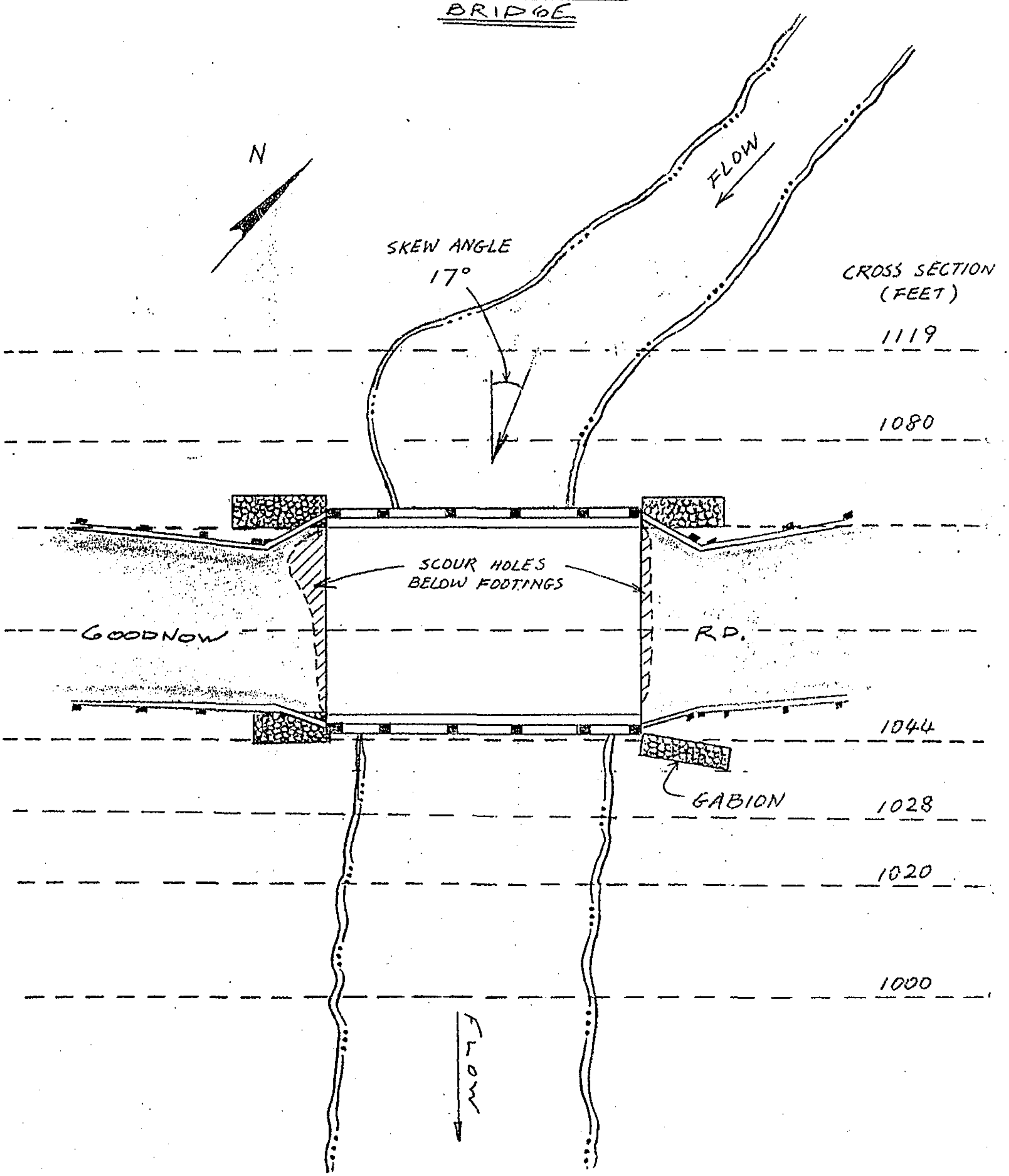

Figure II Schematic of Bridge Alignment and Cross Section Location

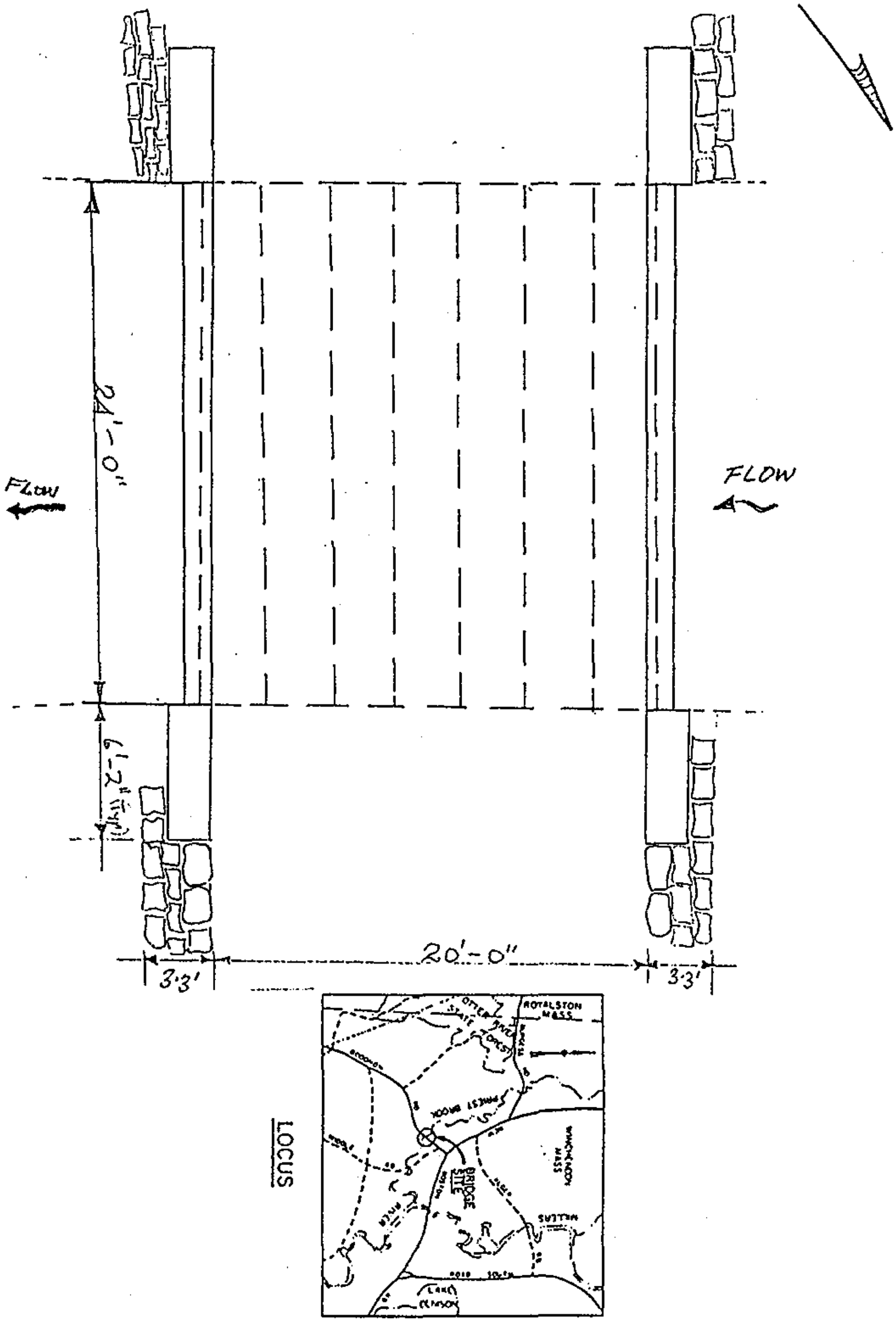

Figure III Plan View of the Bridge

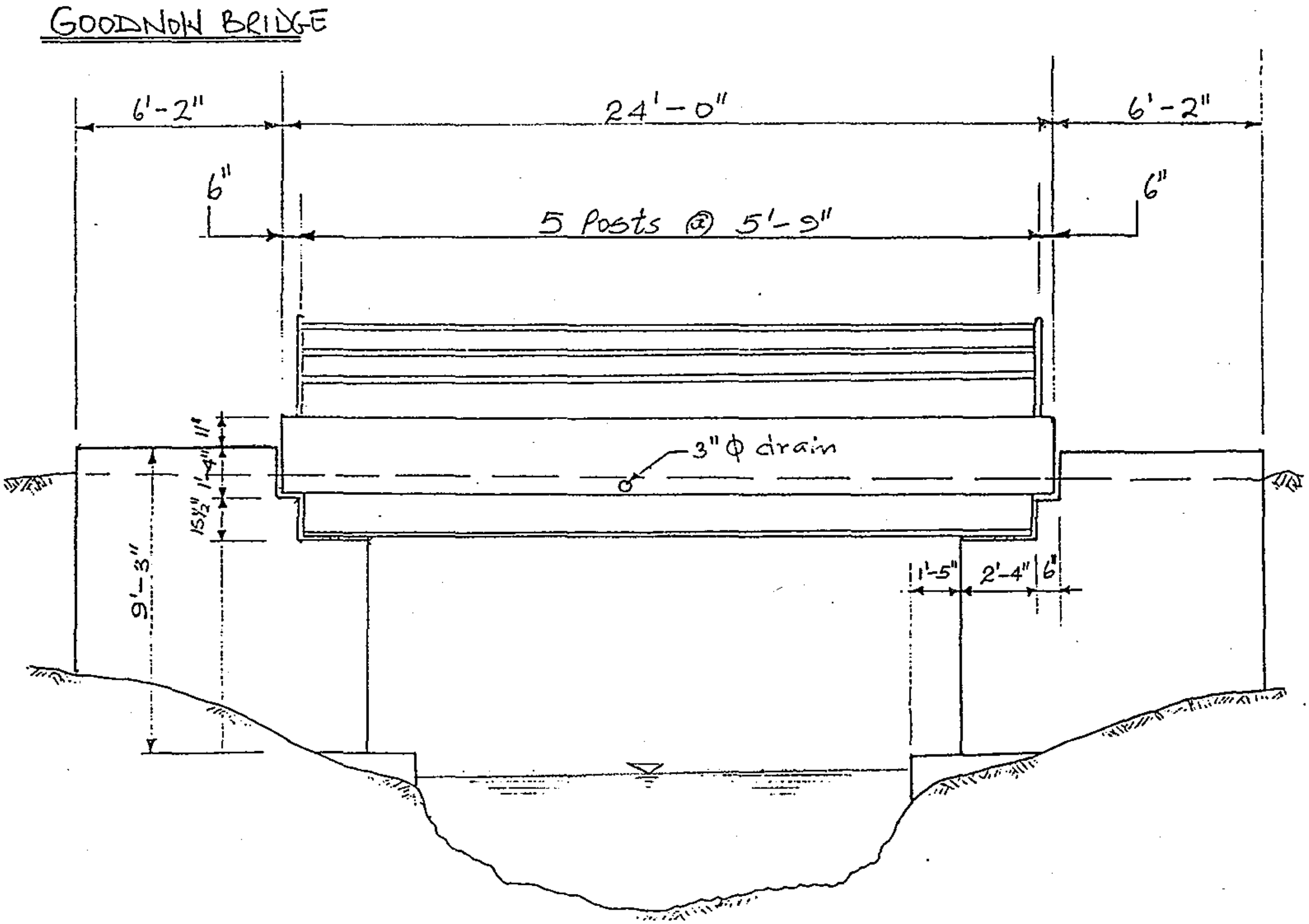

Figure IV Vertical View of the Bridge (looking upstream) flow through the bridge is expected to be restricted significantly because the bridge opening length is much smaller than the stream flow width when the banks are flooded. The streambed in the vicinity of the bridge appears to be in stable condition. However, it appears that high velocity flow has eroded the sand and gravel beneath the bridge abutment footings. The Corps of Engineers' Geotechnical Assessment for Bridge Study (August 1993) reported that a steel bar could be pushed from 0.5 to 3.5 feet into nine scour holes under the south abutment footing and 0.5 to 1.0 feet into six scour holes under the north abutment footing. Locations of scour are depicted schematically in Figure II.

Alignment of the bridge is skewed about 17° counter-clockwise with respect to flow direction (Figure II). At high flow (overbank flow), the skew angle is estimated to be reduced to about 7°. The roadway is slightly skewed with the bridge centerline. The abutments of the bridge are constructed of concrete and stone, while the deck is made of steel beams and concrete at the top.

According to the 1984 inspection report conducted by H.W. Lochner Inc., the bridge seemed to be in good condition with minor items required to be repaired. These included: repairing the rails, abutment footings and under-side of south fascia; cleaning the bearing seat, joint, deck gutters and drains. As reported in the FY'91 C.O.E. Routine Inspection Report and confirmed by our site visit, all of the above repairs appear to have been completed.

3.0 HYDROLOGIC ANALYSIS

3.1 General

Birch Hill Dam is a dry bed flood control dam which only stores water to mitigate downstream flooding during flood periods. The dam is on Millers River 27.3 miles above its junction with the Connecticut River, and has a drainage area of 175 mi^2. Top elevation of the dam is 864 feet N.G.V.D.. The ungated Ogee-type spillway has a crest elevation of 852 feet N.G.V.D. and crest length of 1,190 feet. The spillway has a maximum discharge capacity of 56,600 cubic feet per second (cfs). The reservoir, when filled to spillway crest, has a storage capacity of 49,900 acre-feet, covering a surface area of about 3,200 acres. Goodnow Road Bridge, with a low chord at an elevation of 841.50 feet N.G.V.D., would be submerged when the reservoir is filled to spillway crest.

3.2 Experienced Floods

Flow records on Priest Brook near Winchendon indicate the maximum discharge occurred during the Great New England Hurricane of September 21, 1938. Peak discharge was estimated to be 3000 cfs at gage height of 9.9 feet above gage datum by extending the rating curve above 620 cfs (at gage heights of 8.4 feet above gage datum). The gage datum is at an elevation of 849.67 feet N.G.V.D. The rating curve was obtained by USGS from contracted-opening measurements.

3.3 Discharge Frequencies

Discharge - Frequency relationship at Goodnow Road Bridge is based on the long term gage data recorded at the U.S.G.S. water stage gage #01162500 on Priest Brook upstream from Goodnow Road Bridge. The average discharge of Priest Brook at the gage is 32.6 cfs. The continuous gage record prior to 1962 has occasional diurnal fluctuations at low flows caused by a mill upstream. Prior to 1953, low flows in Priest Brook were regulated by upstream mills and ponds. The flood flow record at the gage is very dependable.

A flood flow frequency analysis was developed based on the U.S. Department of the Interior Publication/Bulletin 17B "Guidelines For Determining Flood Flow Frequency". The Hydrologic Engineering Center (HEC) program HECWRC based on the Water Resource Council methodology was used to analyze the annual peak flows assuming Log Pearson Type III distribution. The analysis resulted in a logarithmic mean, standard deviation and skew of 2.58, 0.26 and 0.60, respectively. The discharge - frequency relationship obtained is shown in Figure V. The discharges with return periods of 10, 25, 50 and 100 years, which correspond to exceedance probabilities of 0.1, 0.04, 0.02 and 0.01, respectively, are indicated in the figure and listed in Table I.

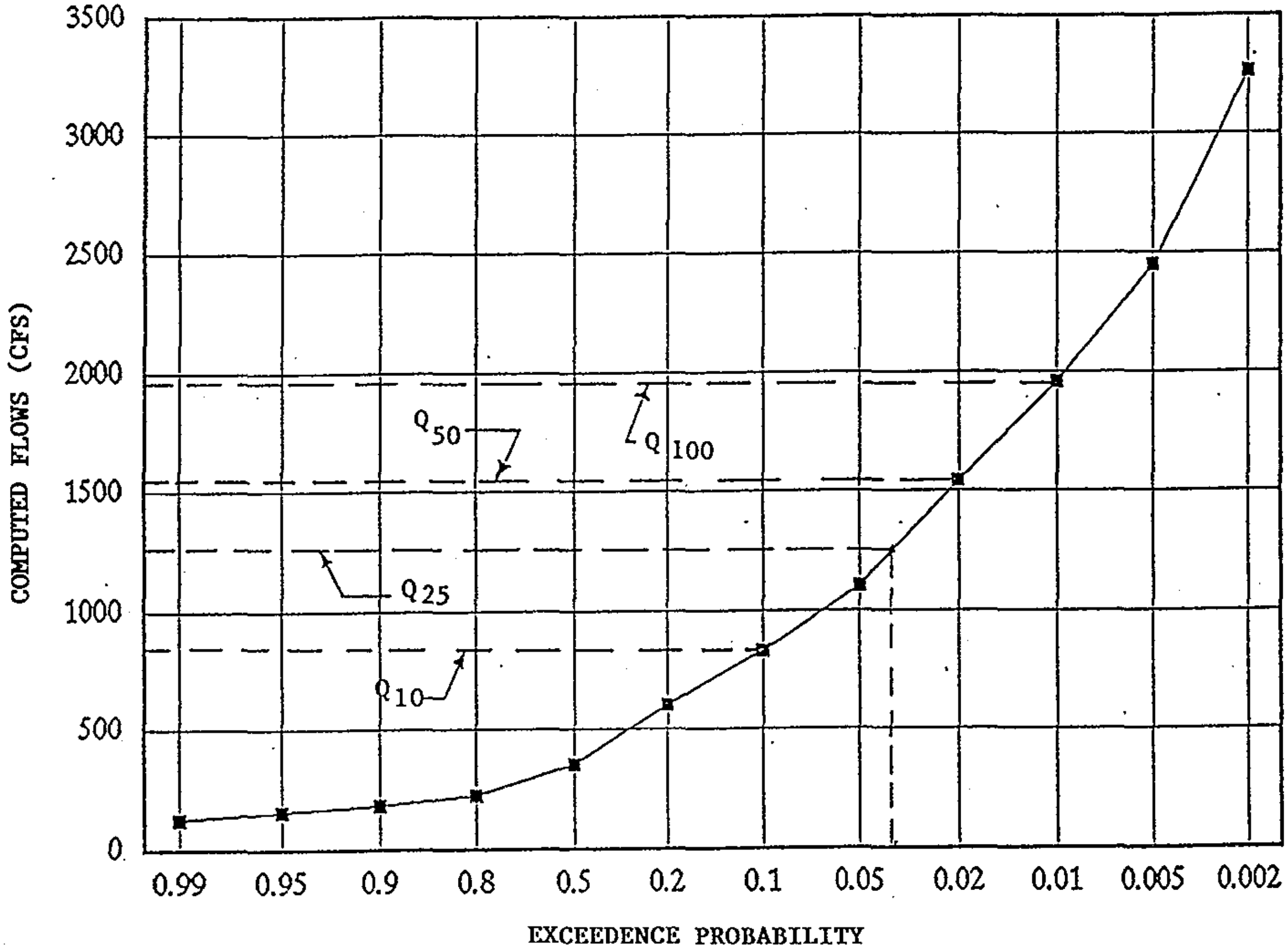

Figure V Discharge - Frequency Relationship

Table I

Discharges at Various Exceedance Probabilities
(at USGS Gage No. 01162500)

Exceedance Probability	Estimated Peak Discharge at Gage (cfs)
0.1	833
0.04	1245
0.02	1540
0.01	1960

The output from the HECWRC computer program was checked with those from FHWA's program, "Hydro" and "Waterboy" that utilizes Water Resource Council (WRC) methodology. The results from the three models are nearly the same. Since Goodnow Road Bridge is located downstream of the gage, and its drainage area (23.58 mi^2) is different from the drainage area (19.4 mi^2) of the gage site, the discharges listed above were adjusted using a regional exponent of 0.70. The adjusted discharges are listed in Table II. Details of hydraulogic computations are presented in Appendix A. The peak discharges obtained herein were used in the hydraulic computations.

3.4 Tailwater Conditions

Although backwater from Birch Hill Dam can periodically inundate the channel at Goodnow Road Bridge, such high tailwater conditions cannot always be assumed to correspond to a specific peak flow at the bridge due to the lag time involved and the large difference in contributing watersheds. From a cursory review of the Birch Hill Dam watershed and its flood attenuating capacity, it is evident that backwater from this impoundment will occur at Goodnow Road Bridge during the recession leg of the hydrograph or well after the peak of the hydrograph at the bridge. Maximum scour velocity at the bridge will occur at the lowest tailwater condition for a particular flood flow. Therefore, backwater effect from Birch Hill Dam was not considered due to the timing of contributing hydrographs and conditions required to develop critical scour velocity.

Table II

Adopted Discharges at Various Exceedance Probabilities

Exceedance Probability	Adjusted Peak Discharge at Bridge Site (cfs)
0.1	955
0.04	1431
0.02	1770
0.01	2253

4.0 HYDRAULIC ANALYSIS

4.1 Backwater Analysis

A backwater analysis was performed at the Goodnow Road Bridge site using the model, "BOSS WSPRO", which is an enhancement of James O. Sherman's 1988 Federal Highway Administration U.S. Geological Survey WSPRO Program for water surface profile computations. The program calculates stages and velocities at all sections. It also calculates discharge distribution (the portion of discharge through the bridge opening and that flowing over the bridge) if the bridge is overtopped by the flow. The minimum cross sections required for bridge hydraulic analysis in WSPRO are shown in Figure VI. The cross sections actually used for the computations in this study are shown in Figure II. Input data include cross section geometry, valley slopes and dimensions and elevations of the bridge structure.

The procedures for selection of input parameters in the hydraulic analyses and the computational results from WSPRO are described below:

Manning roughness coefficients for the channel and flood plains were determined based on mean bed material size and vegetation conditions. The tables provided in the U.S.G.S. Water Supply Paper (#2339) were used as a guideline for this purpose.

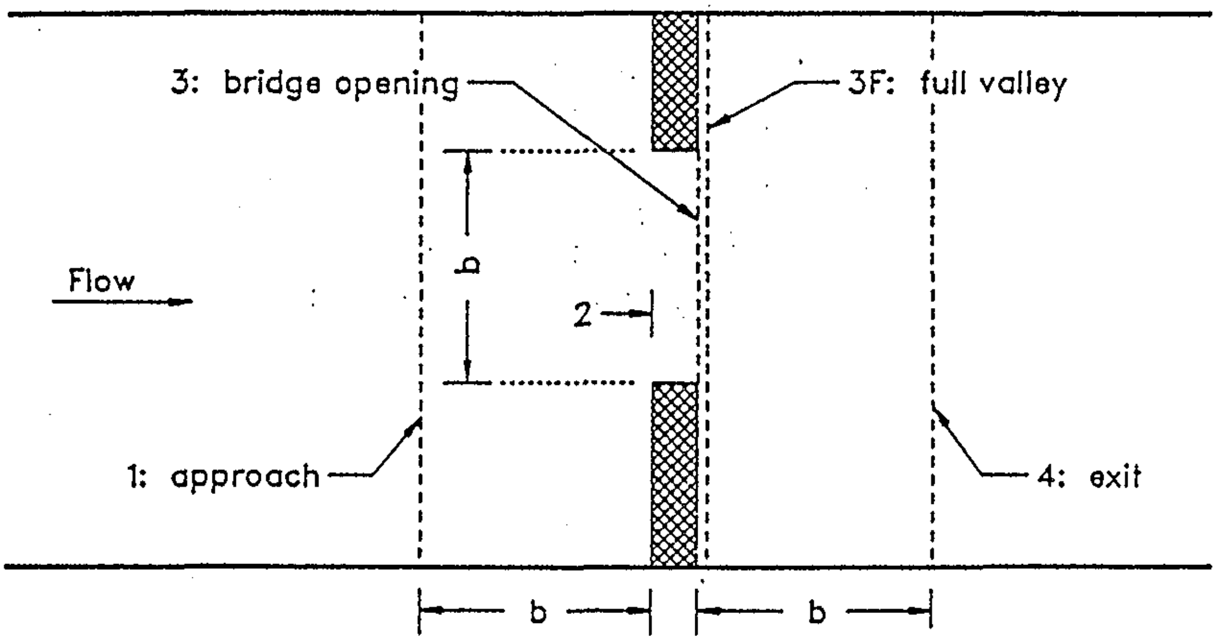

Figure VI Location of Cross-Section Required for Hydraulic Analysis in WSPRO

Loss coefficients were determined based on the outline given in the Bridge Waterways Analysis Model (FHWA/RD-86/108) which states that $K_e = 0 - 1.0$ and $K_c = 0 - 0.5$, where K_e = expansion loss coefficient and K_c = contraction loss coefficient. In the absence of a clear guideline for the selection of K_e and K_c, "WSPRO" run was made using $K_c = 0.1$ and $K_e = 0.5$ initially for sections immediately upstream and downstream from the bridge respectively. K_c and K_e were set at default values for all other sections. From this preliminary run, flow cross-section areas were calculated and used as references for adjusting K_c and K_e. Output from WSPRO showed that conveyance ratios at all sections were within the recommended limits (0.7 - 1.4). No warning messages were present.

The coefficient of discharge for the bridge opening was determined based on the type of the bridge embankments (type 2: sloping embankment without wingwalls) and the skew angle of the bridge (7 degrees for overbank flows). A coefficient of 0.9 was computed by the program.

The starting water surface elevation was determined with the energy gradient method (slope-area method). WSPRO was run using this value and the resulting water surface elevation for the most downstream section was then used as the starting surface elevation.

Output from WSPRO shows that the discharges Q_{10} and Q_{25} maintained open-channel flows through the bridge. The discharges Q_{50} and Q_{100} overtopped the bridge roadway and resulted in orifice flows through the bridge opening. Among the four discharges, Q_{25} yielded the largest velocity, 13.3 ft/sec, at the bridge site. The higher discharges, Q_{50} and Q_{100}, did not yield higher velocities at the bridge because overtopping reduced the flow through the bridge opening.

A trial-and-error procedure was then followed to search for the design discharge, in the neighborhood of Q_{25}, which would yield the maximum velocity with flow close to low chord elevation. The design discharge (Q_{design}) was found to be 1455 cfs which resulted in a velocity of 13.6 ft/sec at the bridge opening. The design flow and velocity were used for the scour analysis. The output from WSPRO was checked with that from the Army Corps of Engineers HEC-2 Model and was found to be in excellent agreement.

Results of the backwater analysis, including water surface elevation at the bridge, discharge and average velocity through the bridge opening for each flood event, are shown in Table III. Water surface elevations resulted from the design flow at all sections, together with cross section profiles, are presented in Figure VII. Longitudinal water surface profiles and energy grade lines for all the flood discharges are shown in Figures VIII through XII, respectively. Details of hydraulic computations are presented in Appendix B.

Table III Results of Backwater Analysis

Exceedance Probability	Total Discharge At Bridge Site (cfs)	Discharge Through Bridge Opening (cfs)	Stage at Bridge Site (ft)	Avg. Velocity Through Bridge Opening (ft/sec)	Flow Overtopping Bridge
0.1	955	955	836.5	11.1	NO
0.04	1431	1431	837.8	13.3	NO
0.02	1770	1349	842.6	8.0	YES
0.01	2253	1505	842.9	9.0	YES
Design	1455	1455	837.8	13.6	NO

4.2 Scour Potential Predicted with FHWA Methodology

Scour at bridge structures is comprised of three components:

(1) Aggradation and degradation: These are long-term streambed elevation changes due to natural or man-induced causes, such as construction of a dam, in the river reach. This type of change occurs with or without bridge structures.

(2) Contraction Scour: Contraction scour occurs as a result of decrease in channel conveyance caused by the intrusion of bridge abutments or piers into the flow.

Figure VII Water Surface Elevation at Cross Sections for the Design Flow (1455 cfs)

(a)

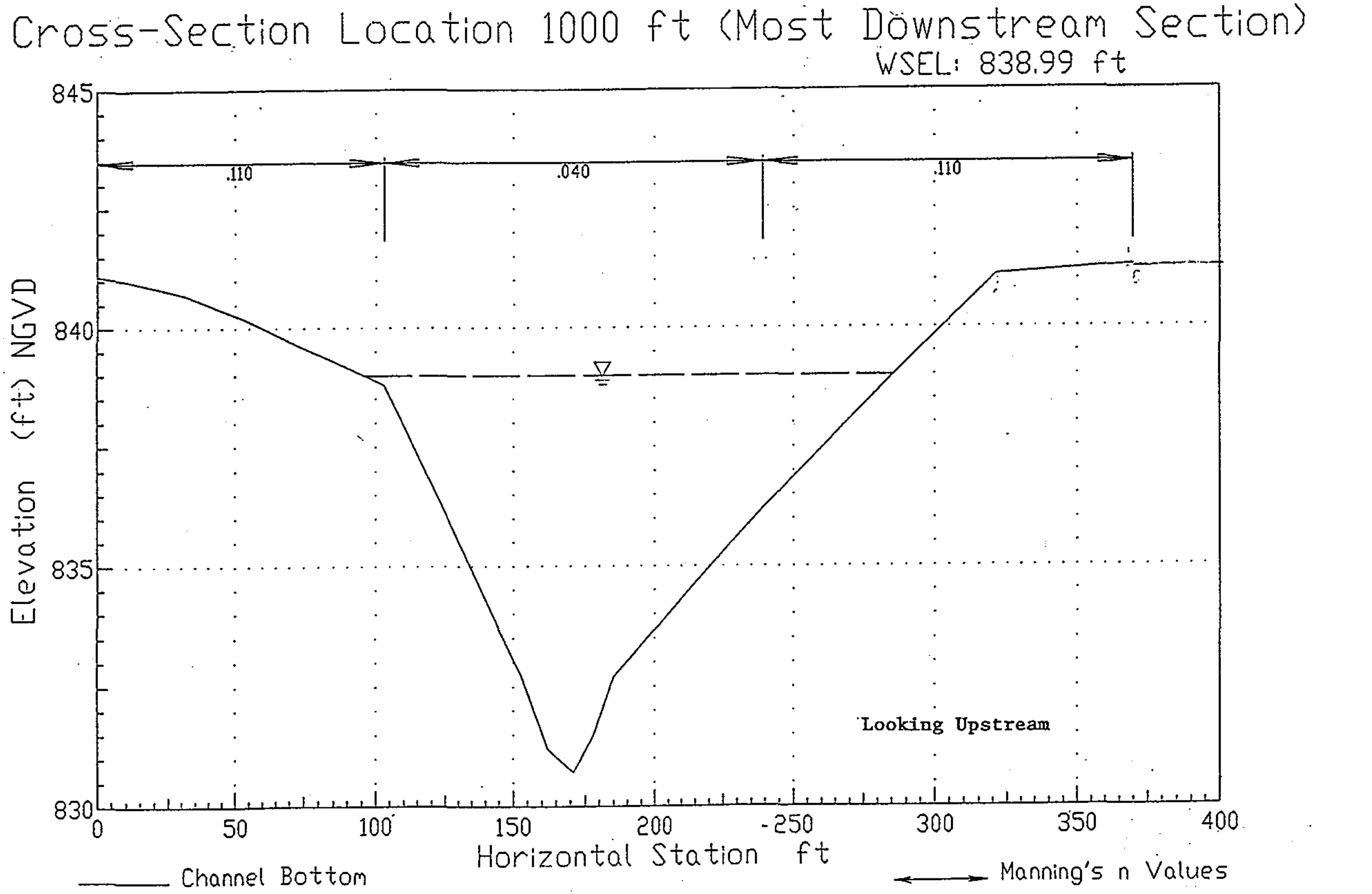

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Figure VII (Continued)

(b)

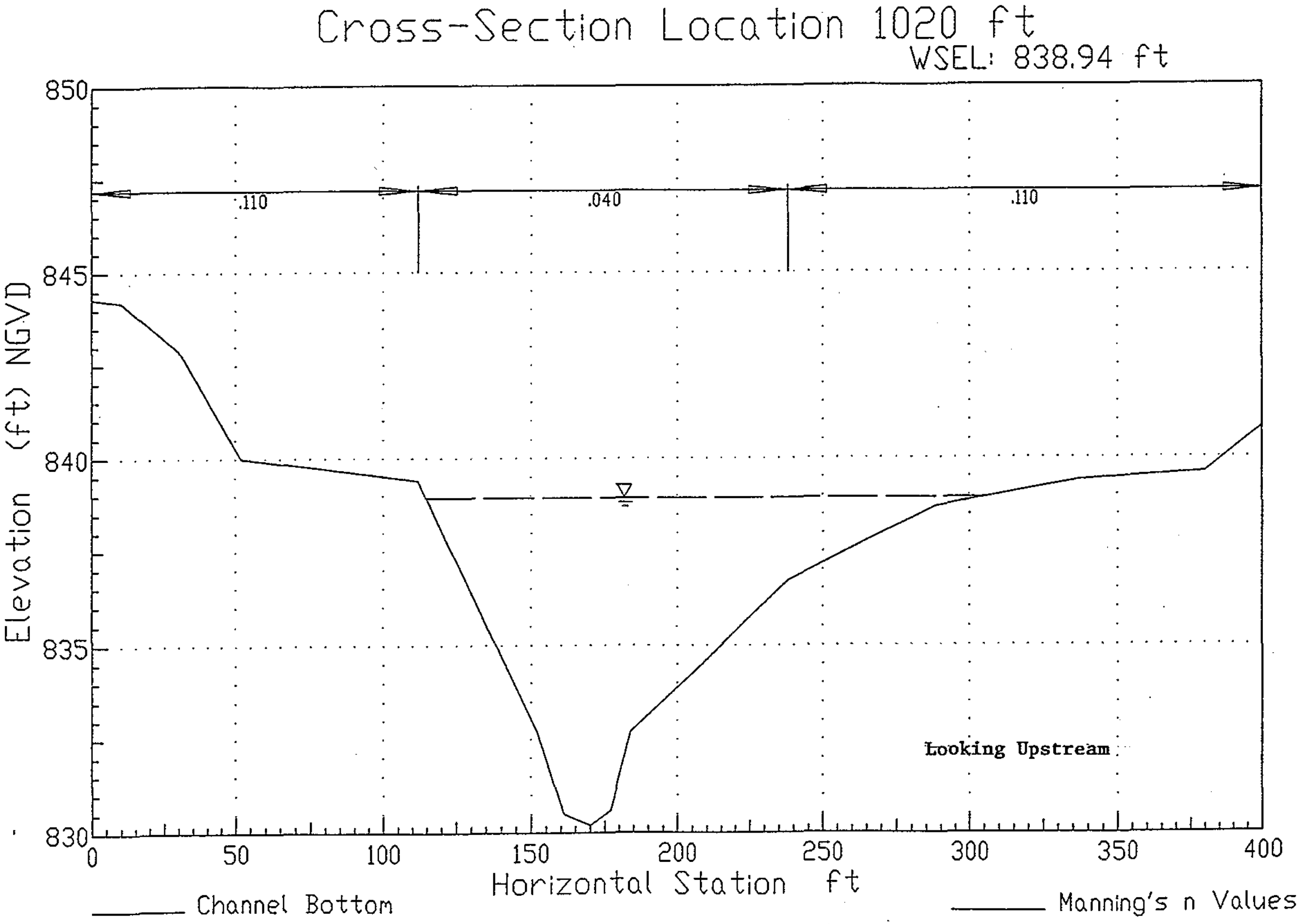


Figure VII (Continued)

(c)

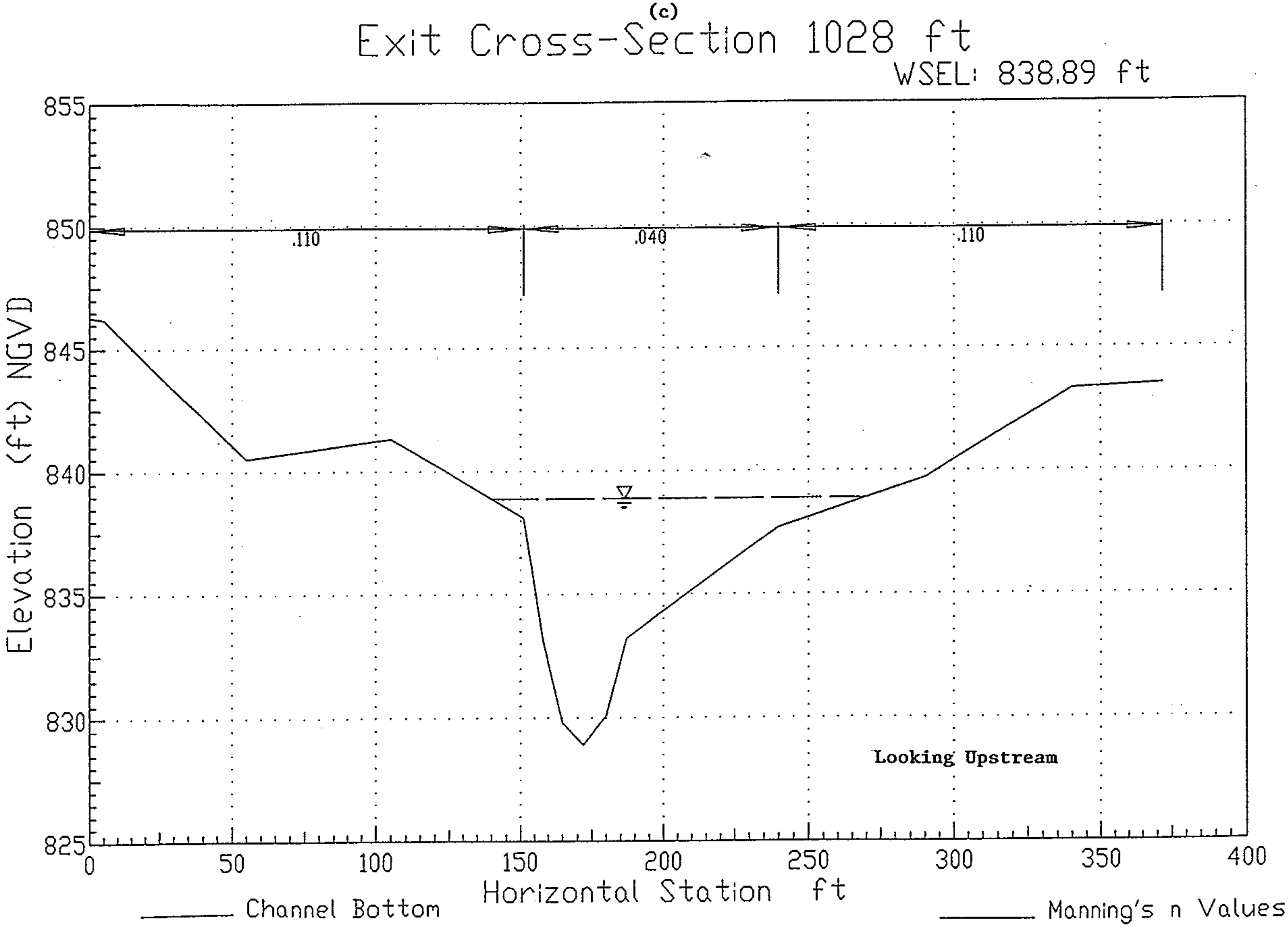


Figure VII (Continued)

(d)

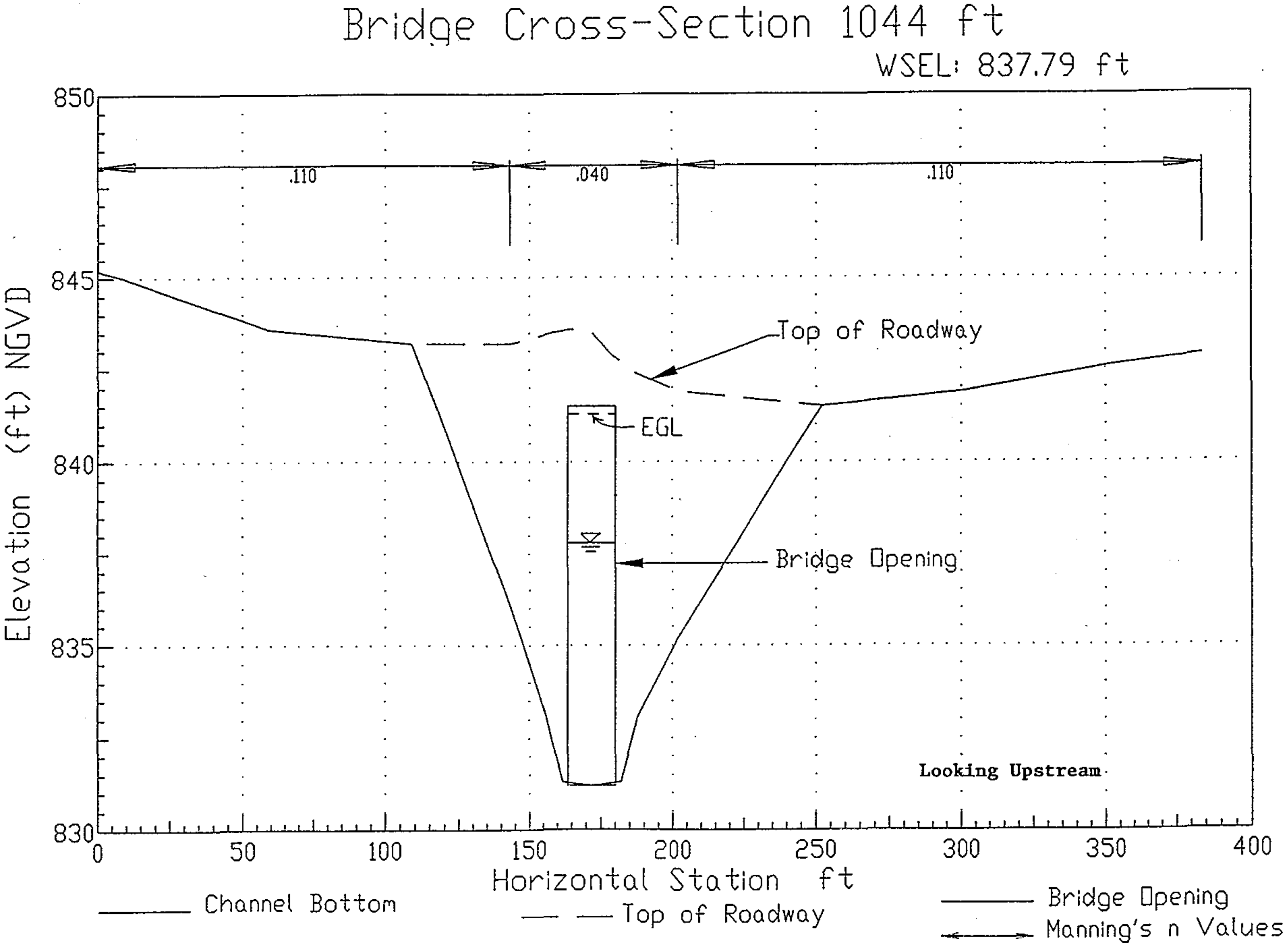


Figure VII (Continued)
(e)

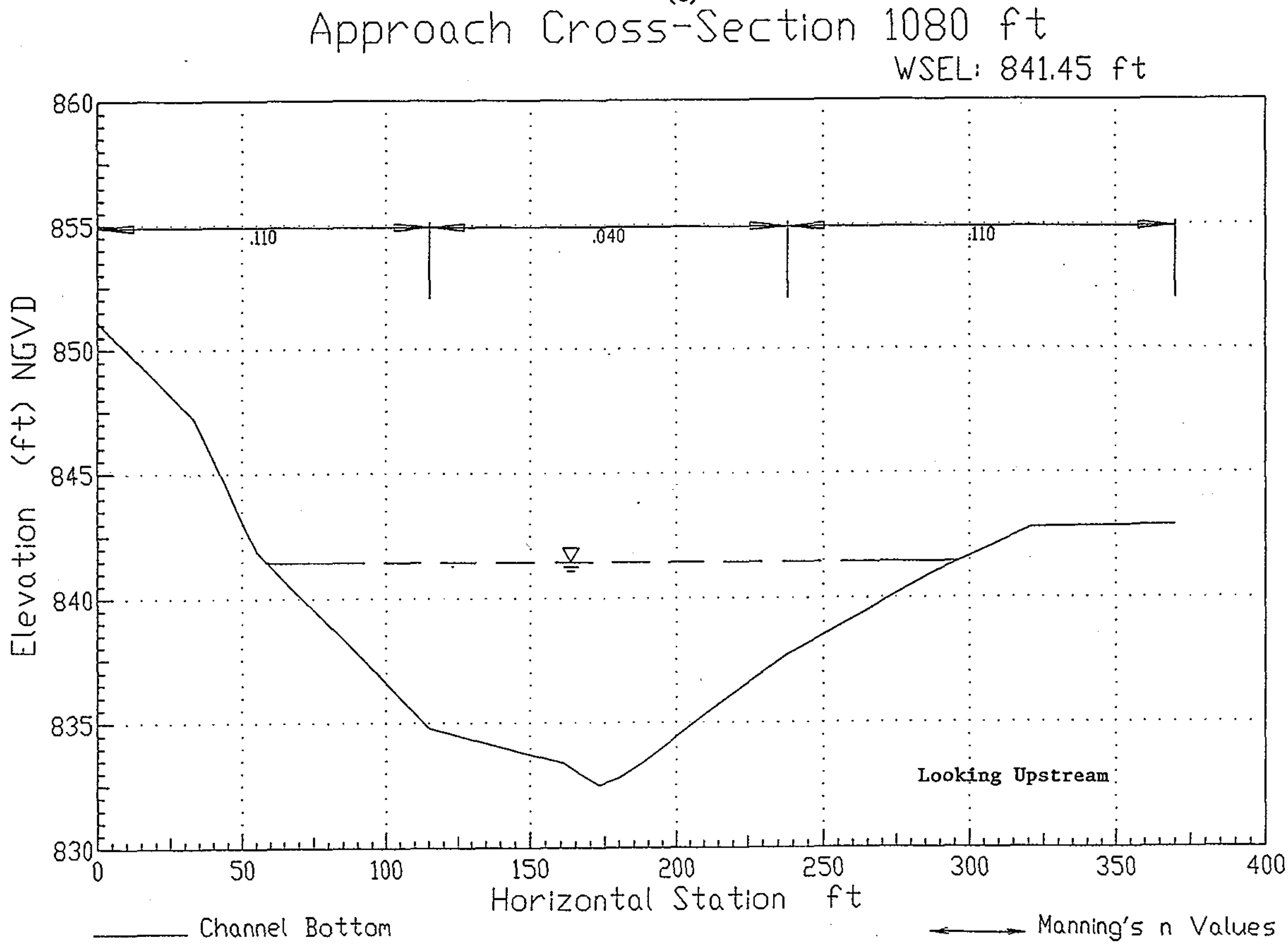


Figure VII (Continued)

(f)

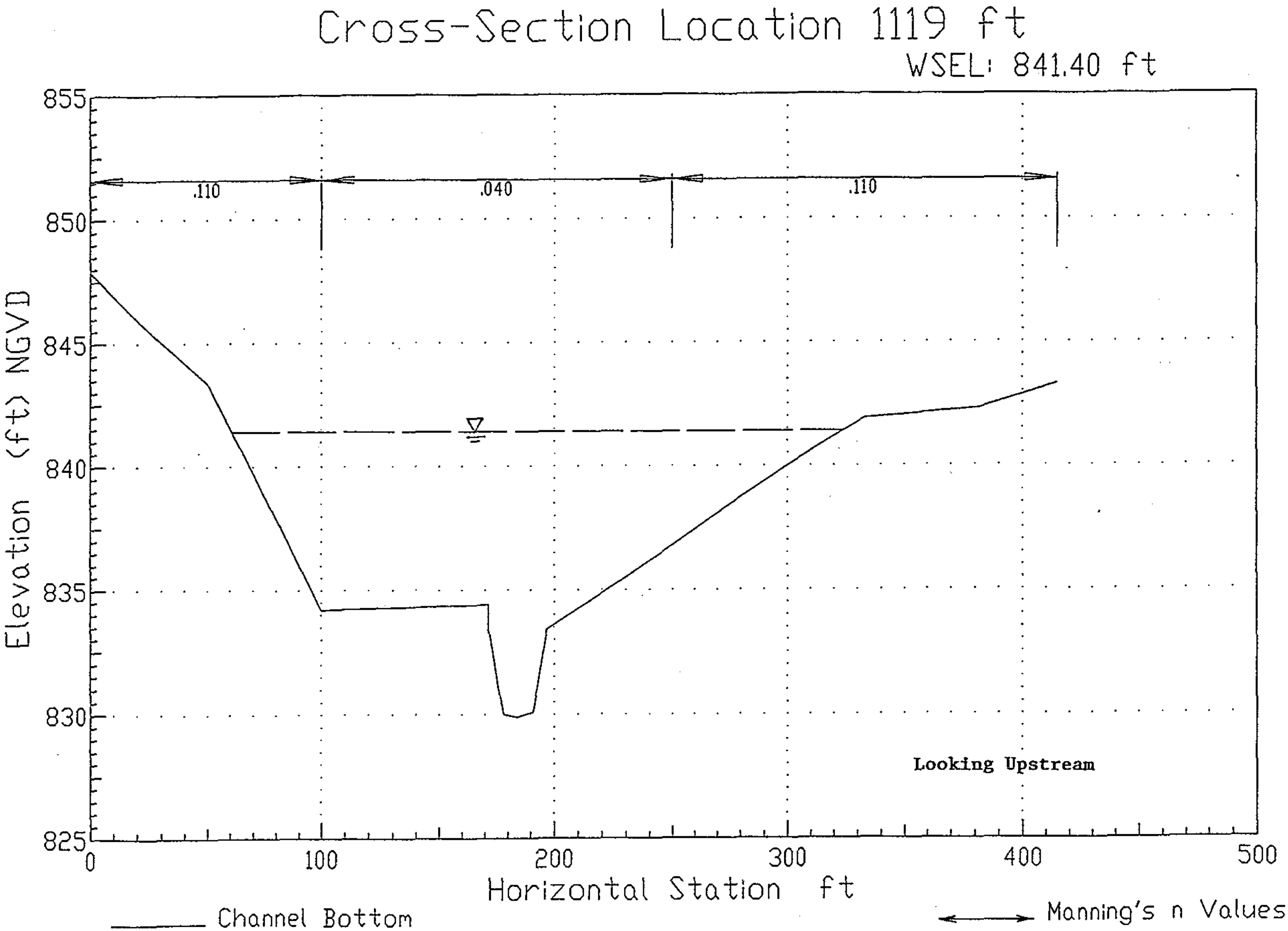


Figure VIII Water Surface Profile and Energy Grade Line for the Design Flow (1455 cfs)

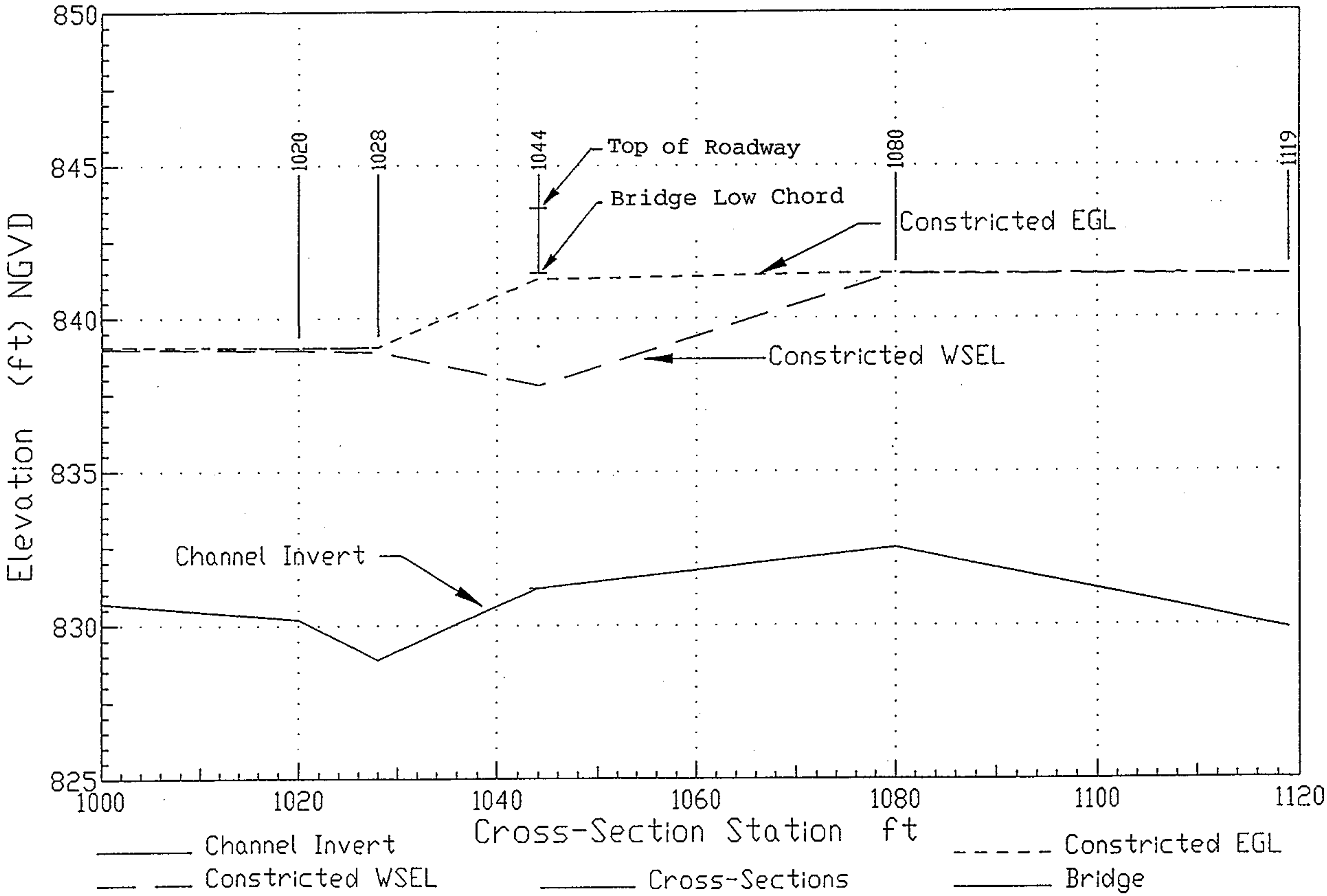


Figure IX Water Surface Profile for Q_{10} = 955 cfs

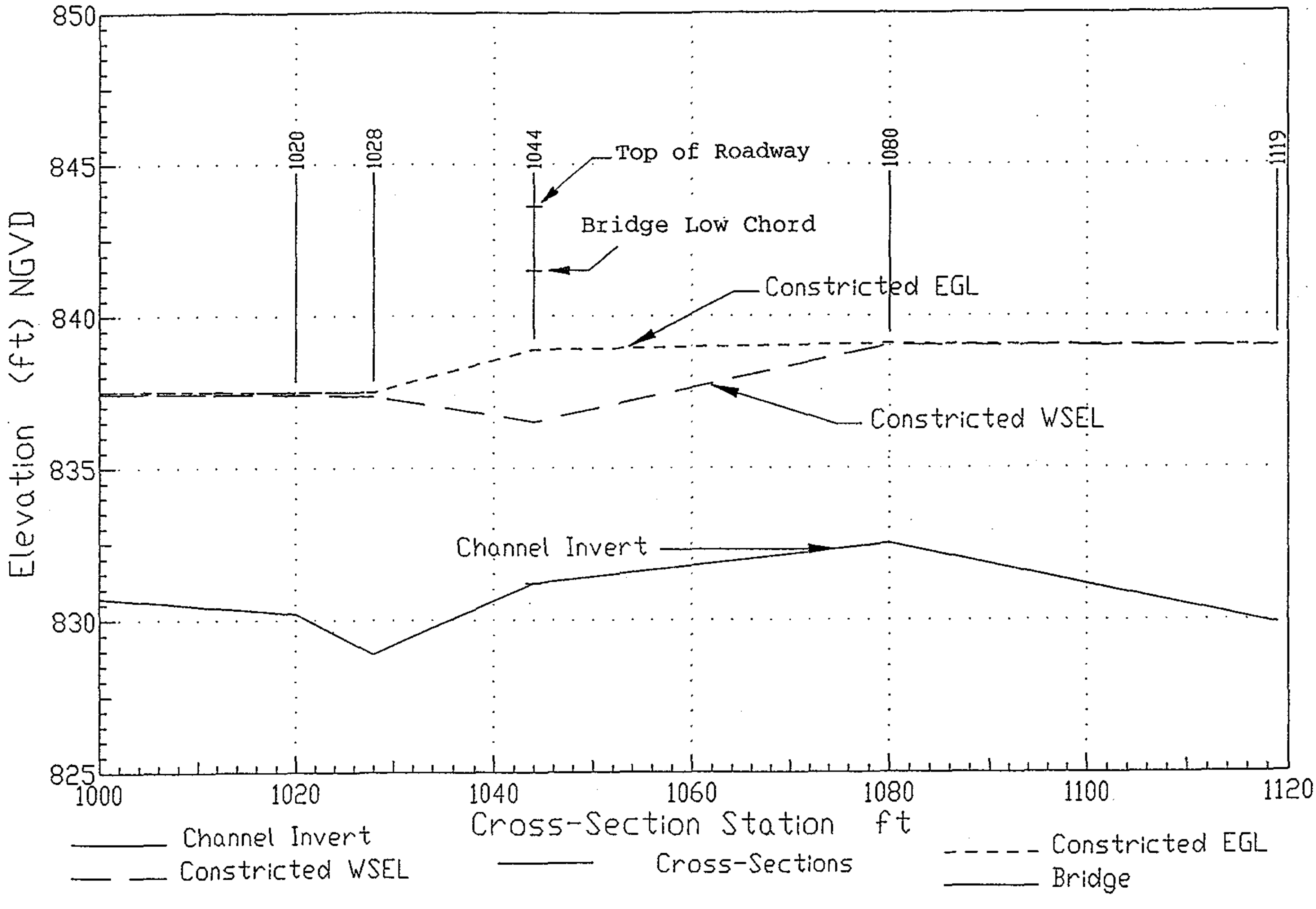


Figure X Water Surface Profile for Q_{25} = 1431 cfs

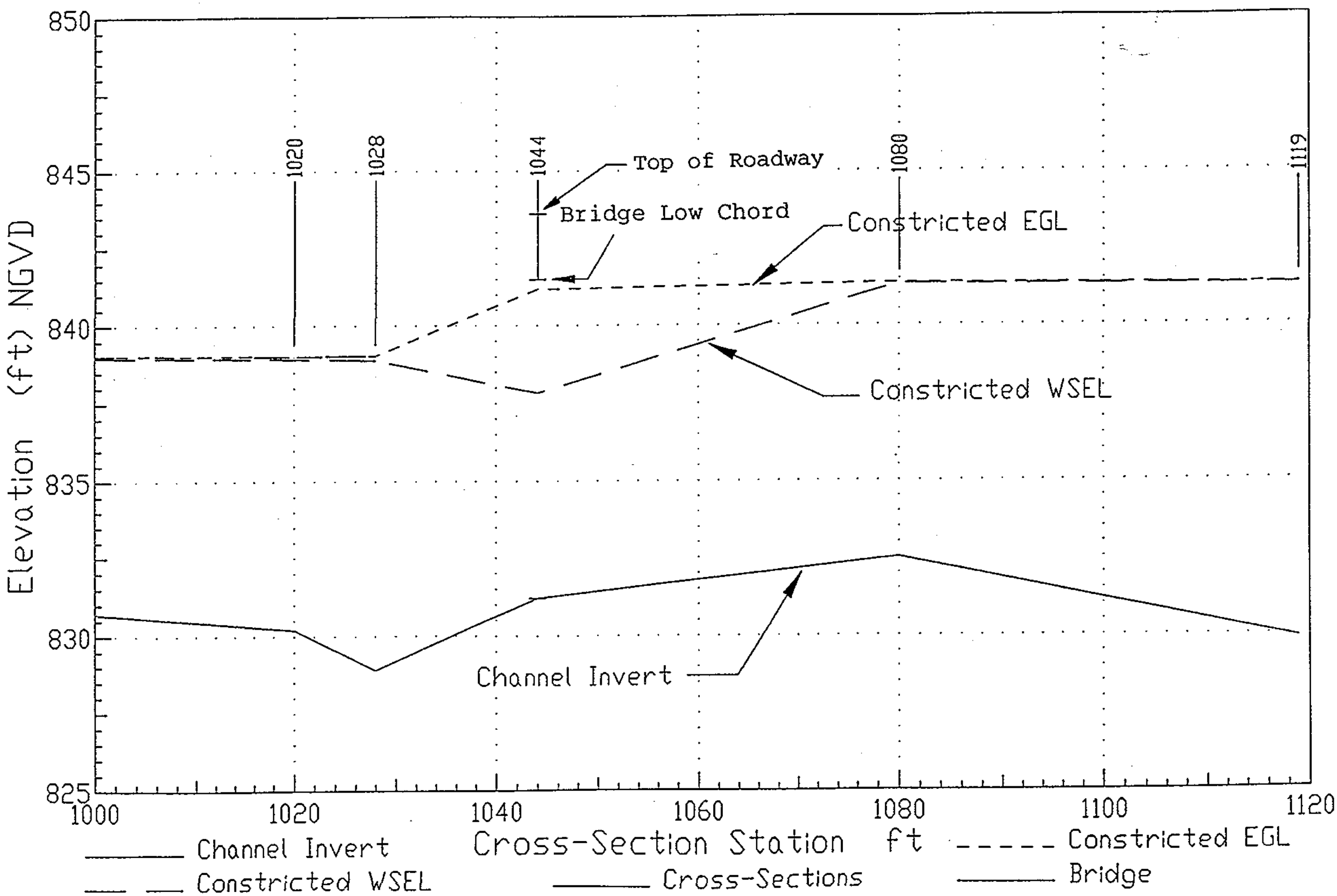


Figure XI   Water Surface Profile for Q_{50} = 1770 cfs

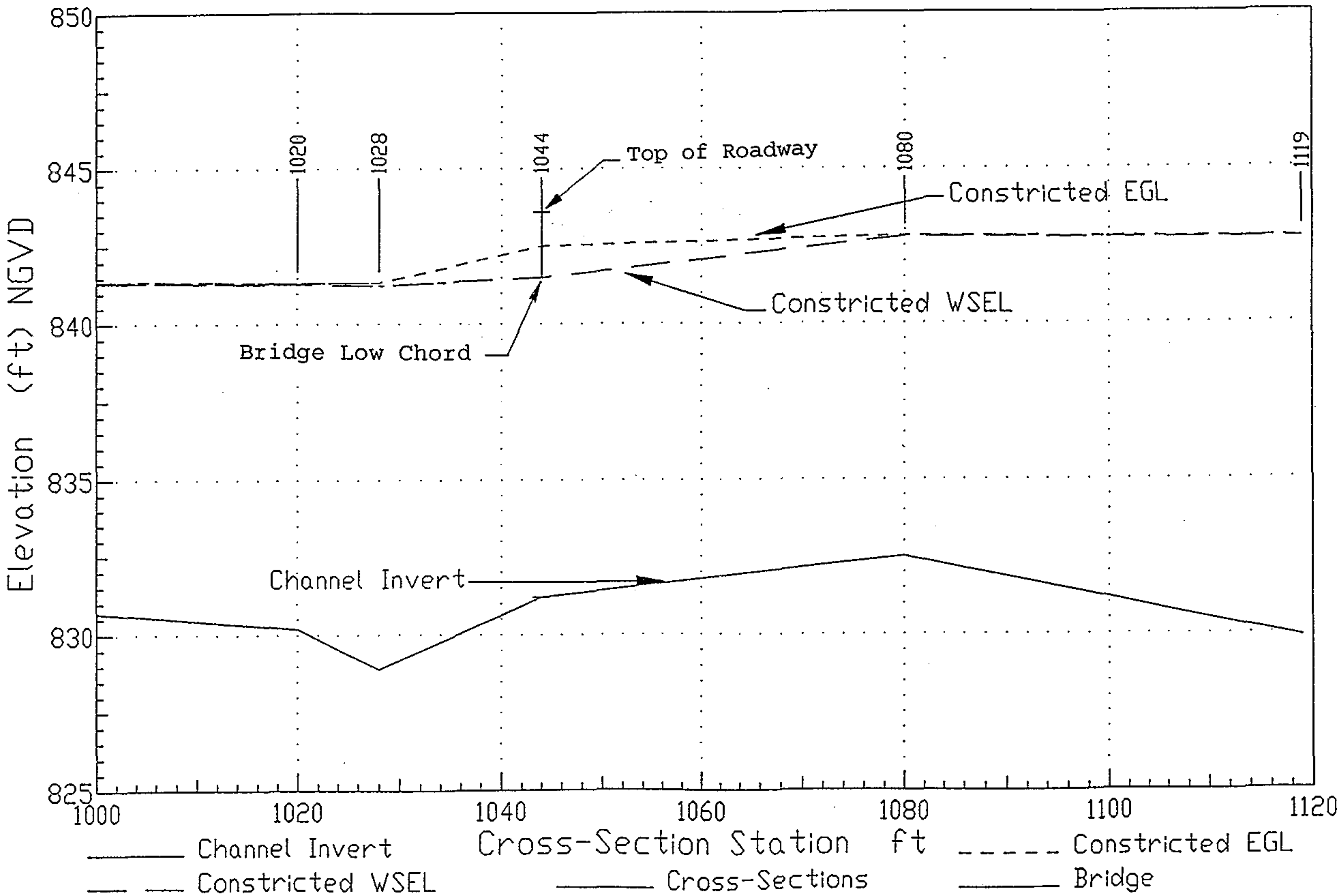
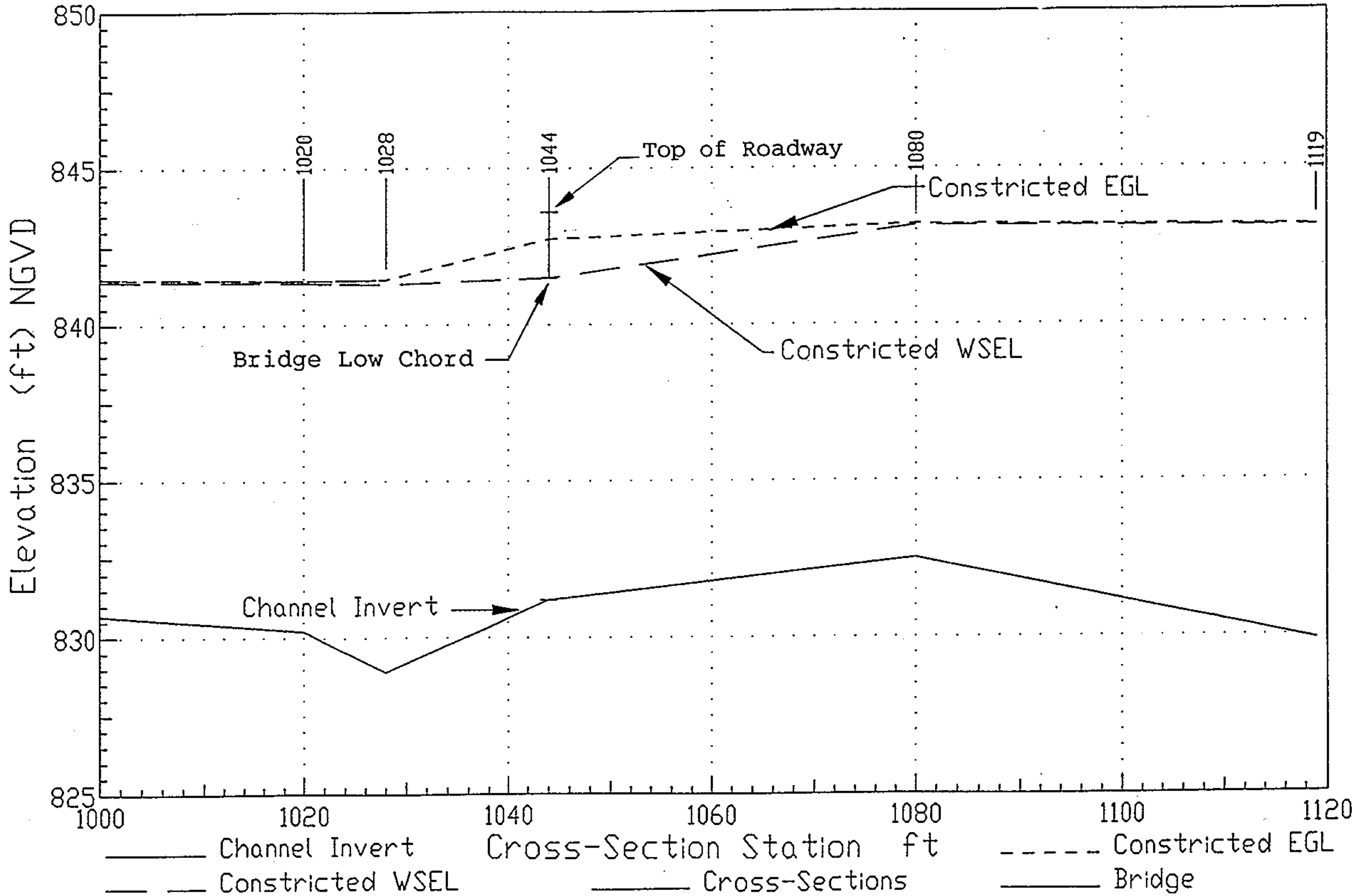


Figure XII Water Surface Profile for Q_{100} = 2253 cfs



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(3) Local Scour: Local scour involves removal of sediment around abutments or piers by the accelerated flow and vortices caused by obstruction of the structures to the flow.

In analyzing scour potential at a bridge crossing, these three components must be considered. For the present study, the analyses have been carried out following the guidance provided in the manual, "Evaluating Scour at Bridges" (FHWA-IP-90-017). Flow condition for the analyses is the design flow with Q_{design} = 1455 cfs which resulted in the maximum velocity at the bridge opening.

4.2.1 Aggradation and Degradation

The passage of the creek is through a marshy area. Brush on the flood plains is very dense. There are scattered trees along the banks. Site observation showed that bed material of the stream is mainly composed of sand. However most portions of the streambed surface are covered by gravel and cobbles due to armoring process. Scattered boulders were also seen in the stream. A geotechnical investigation performed by the Corps of Engineers (1993) shows that the bed material (sand and gravel matrix) at the bridge consists of about 38.7% gravel, 60.6% sand and 0.7% silt. The material has a size range from below 0.07 millimeters (mm) to 60 mm, and was described as poorly graded sand with gravel. The medium size D_{50} is 0.63 mm. The medium size of bed surface material from sand to boulders was estimated to be 1.0 - 1.5 ft by visualization. It is also reported that streambank matrix material characteristics did not appear to be significantly different from streambed matrix material. However, the number and size of cobbles and boulders in the streambank material appeared to be lower than the streambed material.

An ideal method for evaluating long-term change of the stream is to compare the stream cross sections over a period of time. However, there is no survey data available for this type of study. During our site visit, some movement of sand was observed, but the transport of sand in the stream does not necessarily indicate that the streambed is experiencing scouring. Considering the small magnitude of flow velocity (the design discharge yields a velocity of about 1.3 ft/sec at the approach cross section upstream of the bridge), large size of streambed surface material and dense vegetation on the banks, the stream appears to be stable. No significant changes in streambed elevation would be expected.

4.2.2 Contraction Scour

The abutments of Goodnow Road Bridge project slightly, about 3 to 4 feet on each side, into the main channel. Under the condition that overbank flow is forced back to the channel through the bridge opening, the following Laursen's equation (live-bed scour, i.e., scour without sediment transport upstream from the bridge) which is one of the frequently used equations and recommended by FHWA (FHWA-IP-90-017) can be used to calculate contraction scour.

$$\frac{y_2}{y_1} = \left(\frac{Q_{mc2}}{Q_{mc1}}\right)^{\frac{6}{7}} \left(\frac{W_{c1}}{W_{c2}}\right)^{k1} \left(\frac{n2}{n1}\right)^{k2} \text{..........(1)}$$

Scour depth is given as

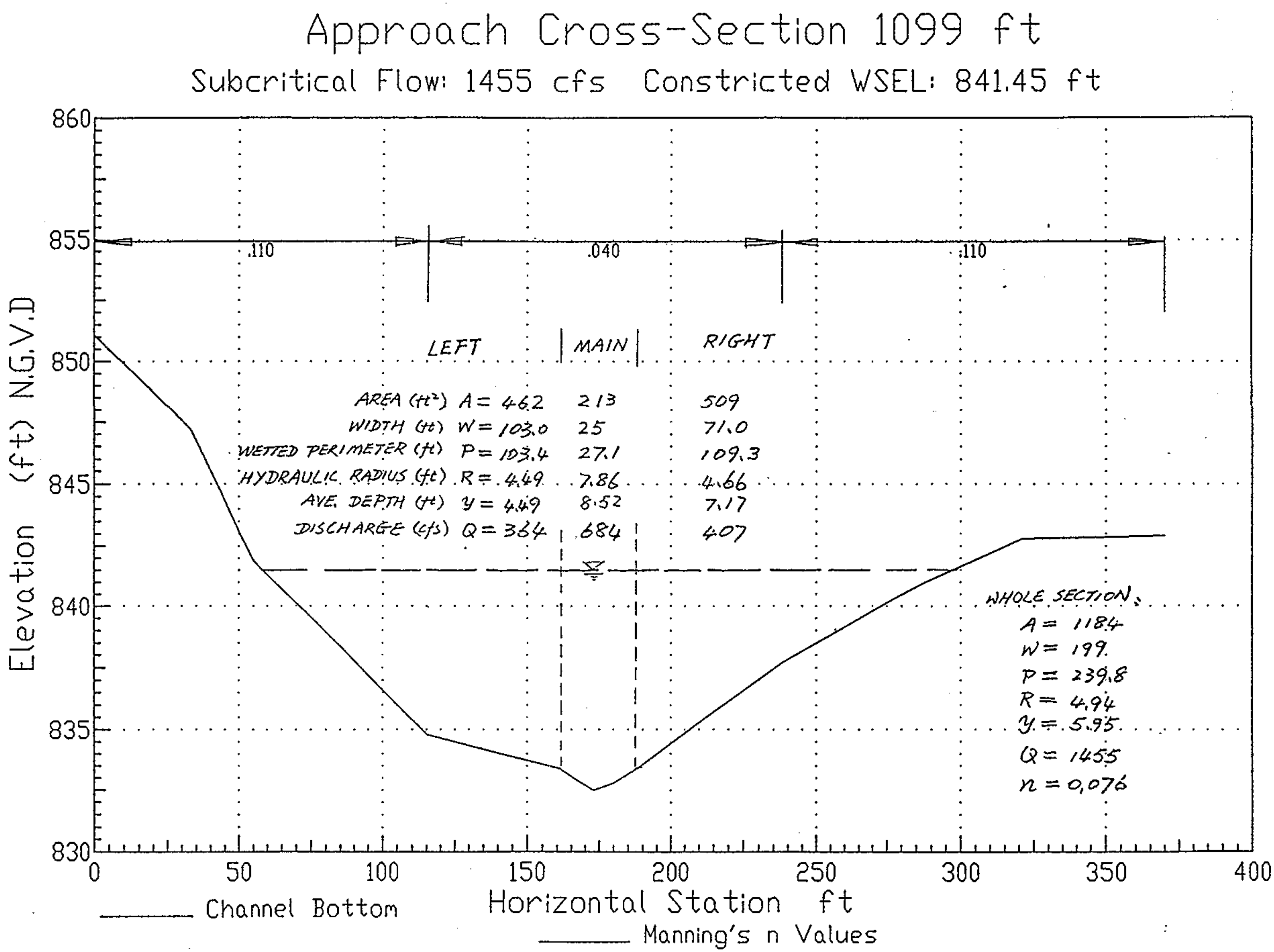
$$y_{cs} = y_2 - y_1 \text{ . . . . (2)}$$

Eq. 1 is applicable to streams with well-graded sand bed. The equation does not account for many factors which could be important in some cases, for example, armoring and vegetation. Notations in Eqs. 1 and 2 and detailed calculation for the present case are presented in Appendix C. Parameters for the approach cross section used in the calculation are also presented in Figure XIII. The scour depth calculated from Eqs. 1 and 2 is y_{cs} = 12.3 ft.

4.2.3 Local Scour

Goodnow Road Bridge does not appear to have protection at its abutments. Therefore, local scour should be evaluated. For the present abutment layout and overbank flow condition, one of the methods recommended by FHWA for calculating local scour is the following Laursen's equation (FHWA-IP-90-017),

Figure XIII Parameters Used for Scour Computations



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$$\frac{Q_0}{q_{mo}y_0} = 2.75\frac{y_{ls}}{y_0}[(\frac{y_{ls}}{4.1y_0}+1)^{\frac{7}{6}}-1]........(3)$$

where y_{ls} = local scour depth. The applicability of Eq. 3 is the same as that of Eq. 1. It does not account for factors such as armoring and vegetation. Notations in the equation and detailed calculation of y_{ls} for the present case are presented in Appendix C. The calculation yields y_{ls}=16.6 ft.

The local scour depth, y_{ls}, calculated from Eq. 3 is additive to the contraction scour depth, y_{cs}, calculated from Eqs. 1 and 2. The total scour depth at the bridge abutment is thus obtained as

$$y_s = y_{cs} + y_{ls}$$

$$= 28.9 \text{ ft}$$

4.3 Critique on Scour Analyses

The scour analyses using the FHWA method resulted in a total scour depth of 28.9 feet (12.3 feet due to contraction scour, and 16.6 feet due to local scour). Site observation and experience indicate that the scour depth thus calculated does not seem realistic and is believed to be overestimated. This type of problem is frequently encountered in engineering calculations because of applying empirical equations which involve selection of parameters. The uncertainty in such a procedure is obvious.

The local scour equations for calculating scour at bridges were developed based primarily on laboratory data or on inductive reasoning from sediment continuity equation. Only limited field data have been used to calibrate the equations. The equations do not account for many factors such as gradation of bed material, armoring, and cohesion. Applying these equations to natural streams usually results in overestimation of scour depth.

A desirable approach for evaluating scour depth for the present case would be the use of a sediment transport model, e.g. BRI-STARS, as suggested by FHWA (FHWA-IP-90-017). However, this is beyond the scope of the present work. Nevertheless, an approximate evaluation of scour potential will be performed which may assist in determining whether there is a need to provide scour countermeasures to the stream reach at the bridge.

As described in Section 4.2.1, the stream under Goodnow Road Bridge has considerable amount of coarse gravel, cobbles and boulders on the bed surface. This bed surface layer of large size material provides protection for underlying sand and gravel against scour. At the velocity of 13.6 ft/sec due to the design discharge (1455 cfs), the size of material which can withstand scour is estimated to be 1.2 feet. The calculation is based on the equation for evaluating degradation limited by armoring (Pemberton and Lara),

$$D = 0.00637\ V^2 \ldots\ldots (3)$$

where D = size of material in feet, and V = flow velocity in feet per second. The coefficient in Eq. 3 is an averaged value of those in Yang's equation and the equation for competent bottom velocity method. It is noted that, for the same velocity (13.6 ft/sec), the stone size D_{30} required for rip-rap revetment (Corps of Engineers, EM 1110-2-1601) is approximately 1.0 feet. The mean diameter of stone calculated from Eq. 3 is therefore reasonable.

The bed surface layer material of Priest Brook near the bridge has an average size of 1.0 - 1.5 feet. It does not appear that any scour which could occur due to contraction of the bridge at the design discharge would be of significance. However, scour of sand and gravel beneath the abutment footings due to vortices could continue because of lack of protection.

5.0 RECOMMENDATION

The analysis based on FHWA scour methodology yielded a scour depth of about 28.9 feet at Goodnow Road Bridge. The estimation appears to be high. The major problem is that the equations used for the scour analysis do not consider many factors, particularly armoring which has significant impact on scour development for the present case. Considering the presence of a bed surface layer of large size material in the stream, it is not expected that scour of streambed due to a flood of the design flow magnitude would be of significance.

The scour holes beneath the abutment footings, however, need to be filled. Further scour could endanger stability of the abutments. A possible method for repairing the footings is to place concrete forms around the outside edges of the abutments and pump concrete into the scour holes as suggested by the Corps of Engineers. The repaired footings should be protected with rip-rap revetment. The size of stone, D_{30}, for the revetment is estimated to be 1.0 feet.

Tree debris accumulation was observed upstream of the bridge. The debris increases flow resistance and should be removed.

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APPENDIX A

Hydrologic Computations

01162500 PRIEST BROOK NEAR WINCHENDON, MA

LOCATION.--Lat 42°40'57", long 72°06'56", Worcester County, Hydrologic Unit 01080202, on right bank 100 ft downstream from highway bridge, 3 mi upstream from mouth, and 3.5 mi west of Winchendon.

DRAINAGE AREA.--19.4 mi².

PERIOD OF RECORD.--Discharge: May 1916 to current year. Monthly discharge only October 1917 to July 1918 (published in WSP 1301) and September 1935 to September 1936.
Water-quality records: Water years 1965-66.

REVISED RECORDS.--WSP 451: 1916. WSP 871: Drainage area. WSP 1051: 1919, 1922-24. WSP 1301: 1917(M), 1919-24(M), 1926-27(M), 1929(M), 1931-35(M).

GAGE.--Water-stage recorder. Concrete control since September 1936. Datum of gage is 849.67 ft (258.979 m) National Geodetic Vertical Datum of 1929. Prior to Sept. 11, 1936, nonrecording gage on left bank at same datum.

REMARKS.--Records good except those for October and November, which are poor. Backwater from beaver dam Oct. 1-9, Oct. 14 to Nov. 13. Prior to 1962, occasional diurnal fluctuation at low flow by mill upstream; prior to 1953, regulation at low flow by mill and ponds. Several observations of water temperature and specific conductance were made during the year.

AVERAGE DISCHARGE.--67 years, 32.6 ft³/s, 22.82 in/yr.

EXTREMES FOR PERIOD OF RECORD.--Maximum discharge, 3,000 ft³/s Sept. 21, 1938, gage height, 9.90 ft, from rating curve extended above 620 ft³/s on basis of contracted-opening measurements at gage heights 8.4 ft and 9.90 ft; minimum, 0.08 ft³/s several times in September 1929.

EXTREMES FOR CURRENT YEAR.--Peak discharges above base of 190 ft³/s and maximum (*):

Date	Time	Discharge (ft³/s)	Gage Height (ft)	Date	Time	Discharge (ft³/s)	Gage Height (ft)
Mar. 20	1145	268	4.55	Apr. 11	1500	*290	4.65

Minimum discharge, 0.34 ft³/s Aug. 26, 27.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983
MEAN VALUES

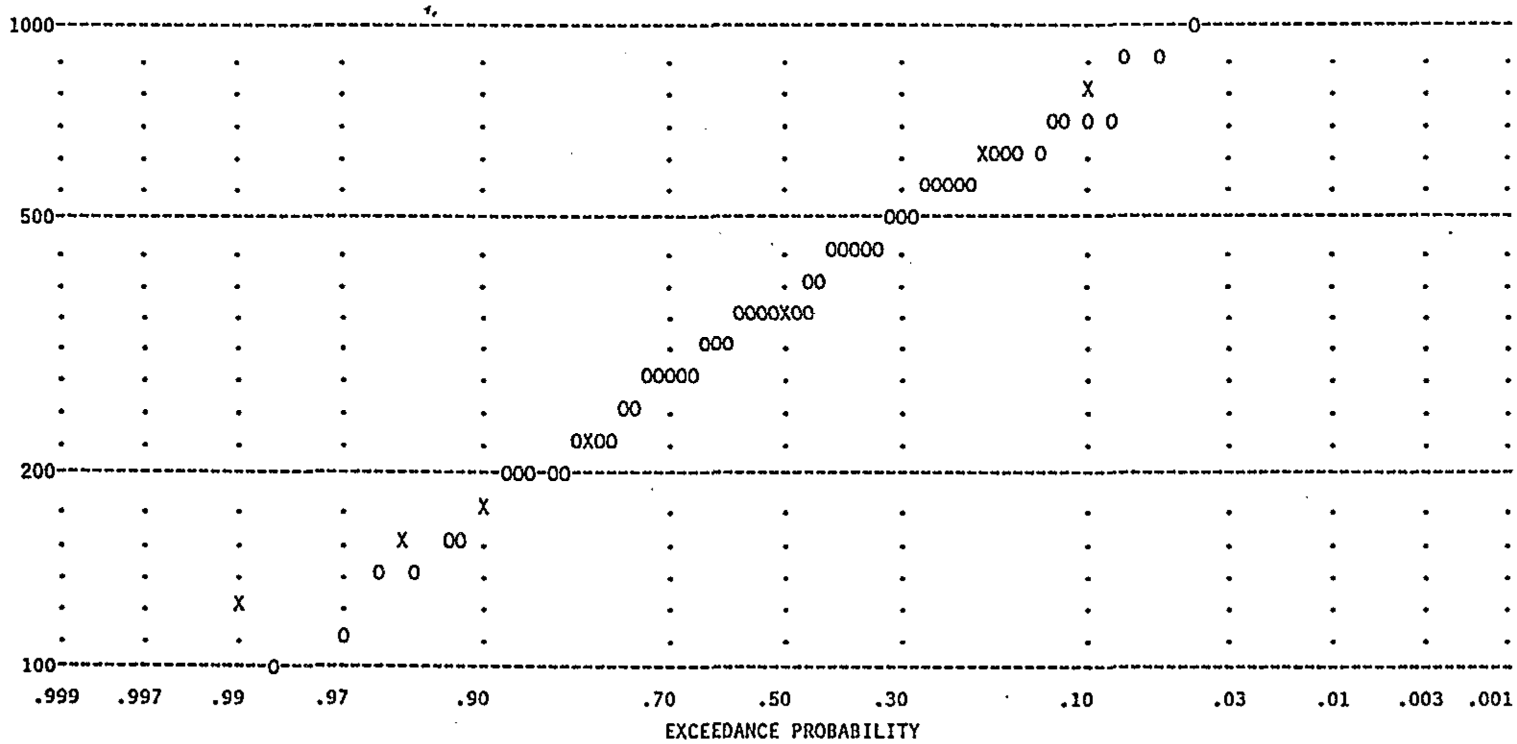
DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	7.0	9.2	23	23	24	17	53	52	103	5.5	1.1	13
2	6.4	10	20	20	23	32	48	57	77	6.8	1.2	6.8
3	5.6	10	17	19	56	72	48	69	59	7.5	1.1	4.0
4	5.0	11	16	15	135	89	66	67	58	5.0	.96	2.6
5	4.5	19	15	14	105	84	71	65	84	4.3	.90	2.0
6	4.2	21	14	17	76	74	65	57	74	8.1	1.2	1.7
7	4.0	15	14	20	57	63	58	47	68	6.3	1.3	1.4
8	7.0	12	13	20	43	59	58	37	65	4.4	.99	1.2
9	19	9.6	12	17	40	60	67	29	50	3.8	.87	1.1
10	21	7.6	10	15	34	67	66	29	39	3.3	.77	1.0
11	16	6.2	9.6	51	28	78	224	26	33	2.8	.81	.96
12	12	5.9	9.4	97	27	118	211	25	28	2.5	1.1	.86
13	9.8	20	8.3	90	26	157	150	24	24	2.3	1.0	.80
14	9.6	50	7.3	70	25	139	115	21	21	2.0	.91	.78
15	9.0	46	7.6	46	23	123	92	22	17	1.9	.77	.71
16	7.5	39	15	35	22	117	76	35	14	1.9	.68	.65
17	6.5	30	47	31	21	114	90	46	11	1.7	.54	.69
18	5.6	24	51	28	21	103	107	47	9.9	2.2	.60	.97
19	5.3	20	41	23	22	117	96	45	8.7	4.7	.68	1.0
20	5.0	17	32	21	20	253	123	44	7.4	2.8	.57	.97
21	4.7	15	27	20	19	242	120	62	6.3	2.1	.45	.90
22	4.5	14	22	19	19	210	103	58	5.5	2.0	.45	2.5
23	4.5	13	19	20	19	161	87	56	4.8	1.8	.55	2.7
24	6.9	12	19	38	19	124	76	93	4.2	1.7	.45	2.0
25	28	11	25	60	19	97	97	113	3.7	1.7	.40	1.6
26	20	11	36	63	18	77	101	90	3.6	1.6	.40	1.3
27	14	10	41	55	17	62	88	76	3.7	1.4	.40	1.2
28	10	9.3	37	42	17	56	74	81	7.3	1.2	.48	1.0
29	8.4	14	36	32	---	64	62	73	12	1.2	2.1	.93
30	6.9	23	32	27	---	67	54	69	8.0	1.2	2.7	1.7
31	7.3	---	27	25	---	61	---	114	---	1.1	11	---
TOTAL	285.2	514.8	703.2	1073	975	3157	2746	1729	910.1	96.8	37.43	59.02
MEAN	9.20	17.2	22.7	34.6	34.8	102	91.5	55.8	30.3	3.12	1.21	1.97
MAX	28	50	51	97	135	253	224	114	103	8.1	11	13
MIN	4.0	5.9	7.3	14	17	17	48	21	3.6	1.1	.40	.65
CFSM	.47	.89	1.17	1.78	1.79	5.26	4.72	2.88	1.56	.16	.06	.10
IN.	.55	.99	1.35	2.06	1.87	6.05	5.27	3.32	1.75	.19	.07	.11

CAL YR 1982 TOTAL 12456.10 MEAN 34.1 MAX 278 MIN 1.7 CFSM 1.76 IN 23.88
WTR YR 1983 TOTAL 12286.55 MEAN 33.7 MAX 253 MIN .40 CFSM 1.74 IN 23.56

```
*********************************          *************************************
*            HECWRC             *          *                                   *
* FLOOD FLOW FREQUENCY ANALYSIS *          *   U.S. ARMY CORPS OF ENGINEERS    *
* PROGRAM DATE:    1 APRIL 1978 *          * THE HYDROLOGIC ENGINEERING CENTER *
* VERSION DATE:    1 APRIL 1987 *          *         609 SECOND STREET         *
* RUN  DATE     AND    TIME:    *          *      DAVIS, CALIFORNIA 95616      *
*    3/ 6/93         14: 6:49   *          * (916) 551-1748 OR (FTS) 460-1748  *
*********************************          *************************************



 INPUT FILE NAME: SCOUR2.DAT
OUTPUT FILE NAME: LPT1



**TITLE CARD(S)**
TT   SCOUR ANALYSIS FOR WINCHENDON, MASS.
TT   WRC - ADJUSTING FOR A HIGH OUTLIER
TT   PRIEST BROOK NEAR WINCHENDON, MA.

**STATION IDENTIFICATION**
ID   01-1625  PRIEST BROOK NEAR WINCHENDON, MA. DA=19.4 SQ. MI.          1919-88

**GENERALIZED SKEW**
     ISTN   GGMSE    SKEW
GS   1625    .000     .60

**SPECIAL STATION INFORMATION**
    IYRA     IYRL   NOUTL  BASEPK
SI  1919     1988      1       0.

**SYSTEMATIC EVENTS**
     70 EVENTS TO BE ANALYZED

**END OF INPUT DATA**
ED +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++



 PRELIMINARY RESULTS
-PLOTTING POSITIONS- 01-1625  PRIEST BROOK NEAR WINCHENDON, MA. DA
****************************************************************
*.....EVENTS ANALYZED......*...........ORDERED EVENTS..........*
*                          *          WATER            WEIBULL  *
* MON DAY  YEAR  FLOW,CFS  *   RANK  YEAR   FLOW,CFS  PLOT POS *
*--------------------------*-----------------------------------*
*   0   0  1919      608.  *     1   1938     3000.     .0141   *
*   0   0  1920      732.  *     2   1936     1840.     .0282   *
*   0   0  1921      457.  *     3   1928     1000.     .0423   *
*   0   0  1922      648.  *     4   1987      871.     .0563   *
*   0   0  1923      530.  *     5   1984      850.     .0704   *
*   0   0  1924      569.  *     6   1960      744.     .0845   *
*   0   0  1925      148.  *     7   1974      737.     .0986   *
*   0   0  1926      230.  *     8   1920      732.     .1127   *
*   0   0  1927      368.  *     9   1940      685.     .1268   *
```

*	0	0	1928	1000.	*	10	1977	664.	.1408	*
*	0	0	1929	319.	*	11	1922	648.	.1549	*
*	0	0	1930	136.	*	12	1959	646.	.1690	*
*	0	0	1931	273.	*	13	1919	608.	.1831	*
*	0	0	1932	457.	*	14	1951	605.	.1972	*
*	0	0	1933	493.	*	15	1924	569.	.2113	*
*	0	0	1934	368.	*	16	1956	568.	.2254	*
*	0	0	1935	352.	*	17	1948	565.	.2394	*
*	0	0	1936	1840.	*	18	1942	550.	.2535	*
*	0	0	1937	210.	*	19	1944	532.	.2676	*
*	0	0	1938	3000.	*	20	1923	530.	.2817	*
*	0	0	1939	370.	*	21	1979	500.	.2958	*
*	0	0	1940	685.	*	22	1933	493.	.3099	*
*	0	0	1941	104.	*	23	1953	479.	.3239	*
*	0	0	1942	550.	*	24	1973	468.	.3380	*
*	0	0	1943	169.	*	25	1932	457.	.3521	*
*	0	0	1944	532.	*	26	1975	457.	.3662	*
*	0	0	1945	280.	*	27	1921	457.	.3803	*
*	0	0	1946	413.	*	28	1980	453.	.3944	*
*	0	0	1947	188.	*	29	1986	450.	.4085	*
*	0	0	1948	565.	*	30	1962	434.	.4225	*
*	0	0	1949	242.	*	31	1946	413.	.4366	*
*	0	0	1950	224.	*	32	1952	389.	.4507	*
*	0	0	1951	605.	*	33	1939	370.	.4648	*
*	0	0	1952	389.	*	34	1934	368.	.4789	*
*	0	0	1953	479.	*	35	1927	368.	.4930	*
*	0	0	1954	325.	*	36	1968	366.	.5070	*
*	0	0	1955	286.	*	37	1972	361.	.5211	*
*	0	0	1956	568.	*	38	1970	359.	.5352	*
*	0	0	1957	207.	*	39	1935	352.	.5493	*
*	0	0	1958	276.	*	40	1969	347.	.5634	*
*	0	0	1959	646.	*	41	1976	339.	.5775	*
*	0	0	1960	744.	*	42	1954	325.	.5915	*
*	0	0	1961	159.	*	43	1929	319.	.6056	*
*	0	0	1962	434.	*	44	1982	311.	.6197	*
*	0	0	1963	305.	*	45	1963	305.	.6338	*
*	0	0	1964	202.	*	46	1983	290.	.6479	*
*	0	0	1965	116.	*	47	1955	286.	.6620	*
*	0	0	1966	209.	*	48	1945	280.	.6761	*
*	0	0	1967	279.	*	49	1967	279.	.6901	*
*	0	0	1968	366.	*	50	1958	276.	.7042	*
*	0	0	1969	347.	*	51	1988	274.	.7183	*
*	0	0	1970	359.	*	52	1931	273.	.7324	*
*	0	0	1971	213.	*	53	1981	263.	.7465	*
*	0	0	1972	361.	*	54	1949	242.	.7606	*
*	0	0	1973	468.	*	55	1926	230.	.7746	*
*	0	0	1974	737.	*	56	1978	230.	.7887	*
*	0	0	1975	457.	*	57	1950	224.	.8028	*
*	0	0	1976	339.	*	58	1971	213.	.8169	*
*	0	0	1977	664.	*	59	1937	210.	.8310	*
*	0	0	1978	230.	*	60	1966	209.	.8451	*
*	0	0	1979	500.	*	61	1957	207.	.8592	*
*	0	0	1980	453.	*	62	1964	202.	.8732	*
*	0	0	1981	263.	*	63	1947	188.	.8873	*
*	0	0	1982	311.	*	64	1943	169.	.9014	*
*	0	0	1983	290.	*	65	1985	161.	.9155	*
*	0	0	1984	850.	*	66	1961	159.	.9296	*
*	0	0	1985	161.	*	67	1925	148.	.9437	*
*	0	0	1986	450.	*	68	1930	136.	.9577	*
*	0	0	1987	871.	*	69	1965	116.	.9718	*

```
*  0  0 1988     274.   *   70  1941      104.    .9859   *
*****************************************************************


-SKEW WEIGHTING -
-----------------------------------------------------------------
BASED ON  70 EVENTS, MEAN-SQUARE ERROR OF STATION SKEW =   .110
DEFAULT OR INPUT MEAN-SQUARE ERROR OF GENERALIZED SKEW =   .302
-----------------------------------------------------------------



 PRELIMINARY RESULTS
-FREQUENCY CURVE- 01-1625  PRIEST BROOK NEAR WINCHENDON, MA. DA
*****************************************************************
*........FLOW,CFS........*             *...CONFIDENCE LIMITS...*
*           EXPECTED     * EXCEEDANCE  *                       *
*  COMPUTED  PROBABILITY * PROBABILITY *  .05 LIMIT  .95 LIMIT *
*------------------------*-------------*-----------------------*
*     3260.      3670.   *     .002    *     4740.      2450.  *
*     2450.      2670.   *     .005    *     3410.      1900.  *
*     1960.      2090.   *     .010    *     2630.      1550.  *
*     1540.      1620.   *     .020    *     2010.      1260.  *
*     1100.      1130.   *     .050    *     1370.       928.  *
*      833.       847.   *     .100    *      998.       718.  *
*      607.       612.   *     .200    *      703.       534.  *
*      354.       354.   *     .500    *      399.       314.  *
*      225.       224.   *     .800    *      256.       194.  *
*      183.       182.   *     .900    *      211.       154.  *
*      157.       155.   *     .950    *      183.       130.  *
*      122.       119.   *     .990    *      146.        98.  *
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
*   FREQUENCY CURVE STATISTICS    *     STATISTICS BASED ON     *
*---------------------------------*-----------------------------*
*  MEAN LOGARITHM        2.5752  *  HISTORIC EVENTS         0  *
*  STANDARD DEVIATION     .2600  *  HIGH OUTLIERS       0      *
*  COMPUTED SKEW          .5479  *  LOW OUTLIERS        0      *
*  GENERALIZED SKEW       .6000  *  ZERO OR MISSING     0      *
*  ADOPTED SKEW           .6000  *  SYSTEMATIC EVENTS      70  *
*****************************************************************



 PRELIMINARY RESULTS
-FREQUENCY PLOT - 01-1625  PRIEST BROOK NEAR WINCHENDON, MA. DA=19.4 SQ. MI.         1919-88
BASED ON COMPUTED VALUES, FLOW IN CUBIC FEET PER SECOND
  5000-----------------------------------------------------------------------------------------------------------------------------
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .           .     O  .       .  X   .
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .           .        .    X  .      .
       .      .       .        .          .                .        .         .               .           .        .       .      .
  2000---------------------------------------------------------------------------------------------------------------X----------------
       .      .       .        .          .                .        .         .               .           O        .       .      .
       .      .       .        .          .                .        .         .               .           .  X     .       .      .
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .           .        .       .      .
       .      .       .        .          .                .        .         .               .      X    .        .       .      .
```



LEGEND - O=OBSERVED EVENT, H=HIGH OUTLIER OR HISTORIC EVENT, L=LOW OUTLIER, Z=ZERO OR MISSING X=COMPUTED CURVE

FINAL RESULTS

-PLOTTING POSITIONS- 01-1625 PRIEST BROOK NEAR WINCHENDON, MA. DA

.....EVENTS ANALYZED......				...........ORDERED EVENTS..........			
					WATER		WEIBULL
MON	DAY	YEAR	FLOW,CFS	RANK	YEAR	FLOW,CFS	PLOT POS
0	0	1919	608.	1	1938	3000.	.0141
0	0	1920	732.	2	1936	1840.	.0282
0	0	1921	457.	3	1928	1000.	.0423
0	0	1922	648.	4	1987	871.	.0563
0	0	1923	530.	5	1984	850.	.0704
0	0	1924	569.	6	1960	744.	.0845
0	0	1925	148.	7	1974	737.	.0986
0	0	1926	230.	8	1920	732.	.1127
0	0	1927	368.	9	1940	685.	.1268
0	0	1928	1000.	10	1977	664.	.1408
0	0	1929	319.	11	1922	648.	.1549
0	0	1930	136.	12	1959	646.	.1690
0	0	1931	273.	13	1919	608.	.1831
0	0	1932	457.	14	1951	605.	.1972
0	0	1933	493.	15	1924	569.	.2113
0	0	1934	368.	16	1956	568.	.2254
0	0	1935	352.	17	1948	565.	.2394
0	0	1936	1840.	18	1942	550.	.2535
0	0	1937	210.	19	1944	532.	.2676
0	0	1938	3000.	20	1923	530.	.2817
0	0	1939	370.	21	1979	500.	.2958
0	0	1940	685.	22	1933	493.	.3099
0	0	1941	104.	23	1953	479.	.3239
0	0	1942	550.	24	1973	468.	.3380
0	0	1943	169.	25	1932	457.	.3521

*	0	0	1944	532.	*	26	1975	457.	.3662	*
*	0	0	1945	280.	*	27	1921	457.	.3803	*
*	0	0	1946	413.	*	28	1980	453.	.3944	*
*	0	0	1947	188.	*	29	1986	450.	.4085	*
*	0	0	1948	565.	*	30	1962	434.	.4225	*
*	0	0	1949	242.	*	31	1946	413.	.4366	*
*	0	0	1950	224.	*	32	1952	389.	.4507	*
*	0	0	1951	605.	*	33	1939	370.	.4648	*
*	0	0	1952	389.	*	34	1934	368.	.4789	*
*	0	0	1953	479.	*	35	1927	368.	.4930	*
*	0	0	1954	325.	*	36	1968	366.	.5070	*
*	0	0	1955	286.	*	37	1972	361.	.5211	*
*	0	0	1956	568.	*	38	1970	359.	.5352	*
*	0	0	1957	207.	*	39	1935	352.	.5493	*
*	0	0	1958	276.	*	40	1969	347.	.5634	*
*	0	0	1959	646.	*	41	1976	339.	.5775	*
*	0	0	1960	744.	*	42	1954	325.	.5915	*
*	0	0	1961	159.	*	43	1929	319.	.6056	*
*	0	0	1962	434.	*	44	1982	311.	.6197	*
*	0	0	1963	305.	*	45	1963	305.	.6338	*
*	0	0	1964	202.	*	46	1983	290.	.6479	*
*	0	0	1965	116.	*	47	1955	286.	.6620	*
*	0	0	1966	209.	*	48	1945	280.	.6761	*
*	0	0	1967	279.	*	49	1967	279.	.6901	*
*	0	0	1968	366.	*	50	1958	276.	.7042	*
*	0	0	1969	347.	*	51	1988	274.	.7183	*
*	0	0	1970	359.	*	52	1931	273.	.7324	*
*	0	0	1971	213.	*	53	1981	263.	.7465	*
*	0	0	1972	361.	*	54	1949	242.	.7606	*
*	0	0	1973	468.	*	55	1926	230.	.7746	*
*	0	0	1974	737.	*	56	1978	230.	.7887	*
*	0	0	1975	457.	*	57	1950	224.	.8028	*
*	0	0	1976	339.	*	58	1971	213.	.8169	*
*	0	0	1977	664.	*	59	1937	210.	.8310	*
*	0	0	1978	230.	*	60	1966	209.	.8451	*
*	0	0	1979	500.	*	61	1957	207.	.8592	*
*	0	0	1980	453.	*	62	1964	202.	.8732	*
*	0	0	1981	263.	*	63	1947	188.	.8873	*
*	0	0	1982	311.	*	64	1943	169.	.9014	*
*	0	0	1983	290.	*	65	1985	161.	.9155	*
*	0	0	1984	850.	*	66	1961	159.	.9296	*
*	0	0	1985	161.	*	67	1925	148.	.9437	*
*	0	0	1986	450.	*	68	1930	136.	.9577	*
*	0	0	1987	871.	*	69	1965	116.	.9718	*
*	0	0	1988	274.	*	70	1941	104.	.9859	*

---

* NOTE- PLOTTING POSITIONS BASED ON-HISTORIC PERIOD (H) = 70 *
* NUMBER OF HISTORIC EVENTS PLUS HIGH OUTLIERS(Z) = 1 *
* WEIGHTING FACTOR FOR SYSTEMATIC EVENTS (W) = 1.0000 *

****

-OUTLIER TESTS -

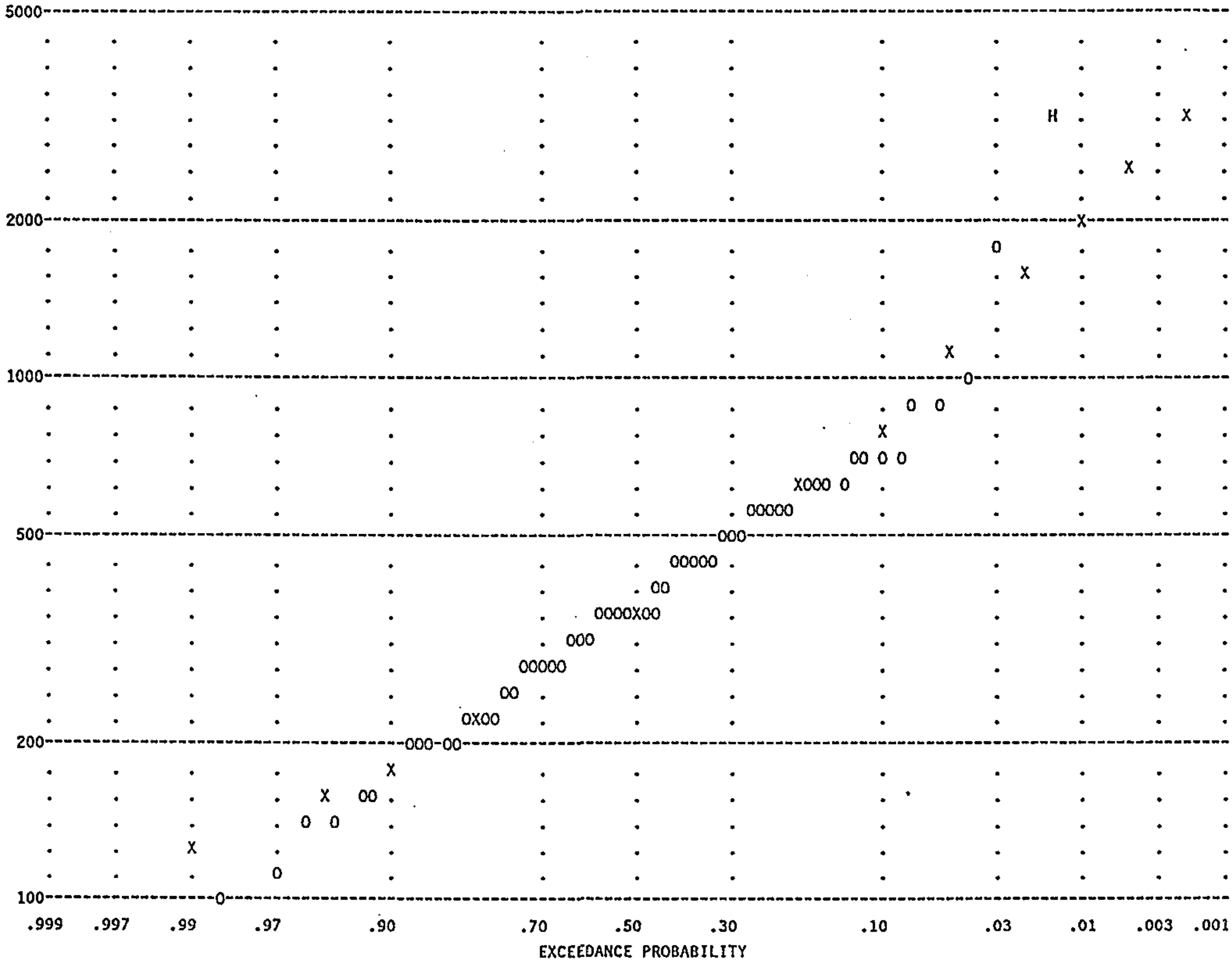
LOW OUTLIER TEST

BASED ON 70 EVENTS, 10 PERCENT OUTLIER TEST VALUE K(N) = 2.893

FINAL RESULTS

-FREQUENCY PLOT - 01-1625 PRIEST BROOK NEAR WINCHENDON, MA. DA=19.4 SQ. MI. 1919-88

BASED ON COMPUTED VALUES, FLOW IN CUBIC FEET PER SECOND

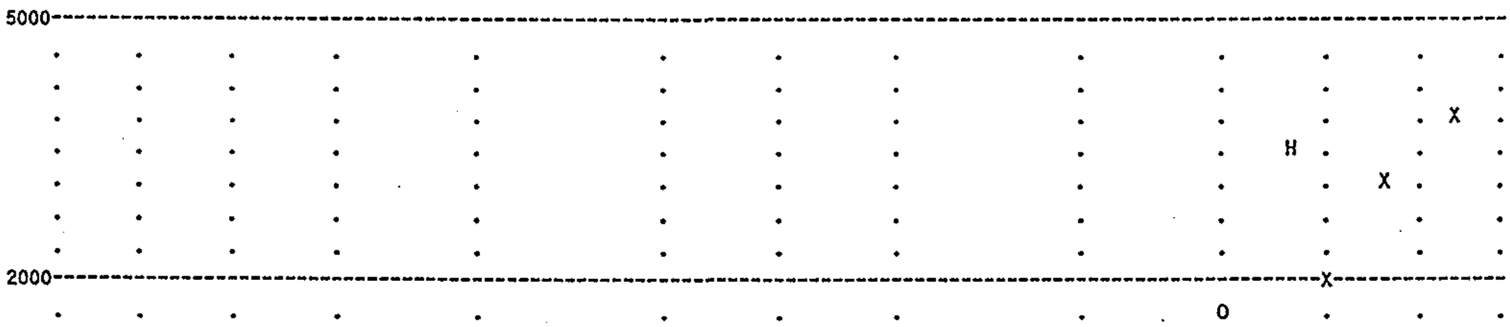


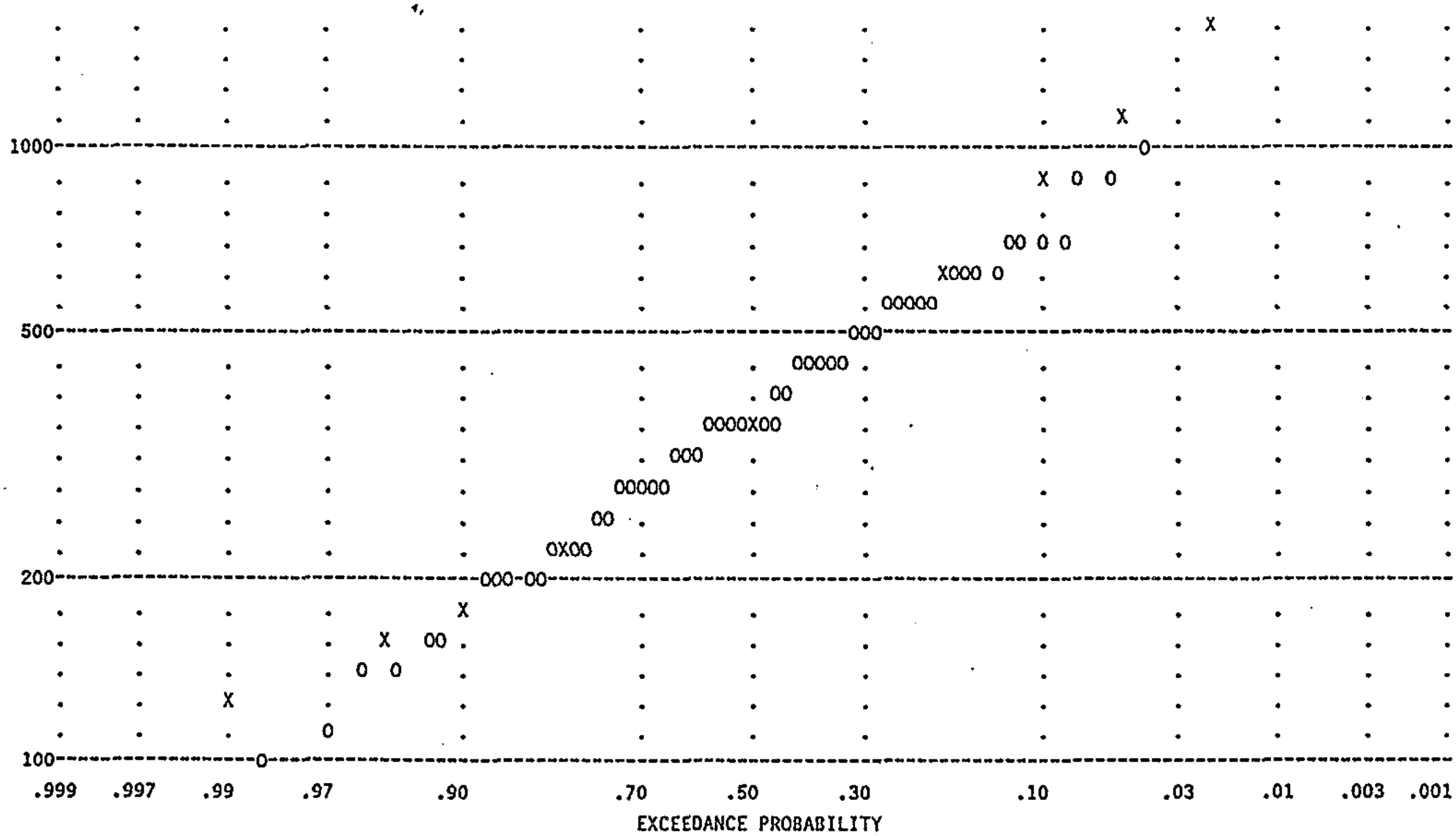
LEGEND - O=OBSERVED EVENT, H=HIGH OUTLIER OR HISTORIC EVENT, L=LOW OUTLIER, Z=ZERO OR MISSING X=COMPUTED CURVE

FINAL RESULTS

-FREQUENCY PLOT - 01-1625 PRIEST BROOK NEAR WINCHENDON, MA. DA=19.4 SQ. MI. 1919-88

BASED ON EXPECTED PROBABILITY ADJUSTMENT, FLOW IN CUBIC FEET PER SECOND





LEGEND - O=OBSERVED EVENT, H=HIGH OUTLIER OR HISTORIC EVENT, L=LOW OUTLIER, Z=ZERO OR MISSING X=COMPUTED CURVE

```
++++++++++++++++++++++++
+ END OF RUN           +
+ NORMAL STOP IN HECWRC +
++++++++++++++++++++++++
```

Project: Corp of Engrs.
Job No.: JC 151-II
Sheet No:
Subject: Goodnow Rd Bridge Scour
Computed By: CAA
Date: 2/22/93.
Detail: Priest Brook @ Goodnow Rd.
Checked By:
Date:

Drainage Area of Priest Brook
up to the Gage station # 01162500

Office estimation = 19.17 $miles^2$

U.S. Geological Survey = 19.40 $miles^2$

Use 19.40 $miles^2$

Storage area = 2.47%
(USGS)

Use 2.47 + 0.5 = 2.97

Drainage Area Between Gage Station and Goodnow Bridge

Office Estimation = 4.18 $miles^2$

use 4.18 $miles^2$

∴ Total Drainage Area

(19.40 + 4.18) $miles^2$

= 23.58 $miles^2$

Project: Corp of Engrs - Waltham
Job No.:
Sheet No.:
Subject: Goodnow Road Bridge
Computed By: GAA
Date: 4/21/93
Detail: Scour Analysis
Checked By:
Date:

$$Q_{0.1} = 84.98 A^{0.760} St^{-0.166}$$

$$= 84.98 (19.4)^{.760} (2.97)^{-0.166} = \underline{\underline{675.41\ ft^3/s}}$$

$$Q_{0.04} = 114.9 A^{0.775} St^{-0.195}$$

$$= 114.9 (19.4)^{0.775} (2.97)^{-0.195}$$

$$= \underline{925.08\ ft^3/s}$$

$$Q_{0.02} = 141.9 A^{0.785} St^{-0.217}$$

$$= 141.9 (19.4)^{0.785} (2.97)^{-0.217}$$

$$= \underline{1{,}149\ ft^3/s}$$

$$Q_{0.01} = 172.7 A^{0.797} St^{-0.237}$$

$$= 172.7 (19.4)^{0.797} (2.97)^{-0.237}$$

$$= \underline{1{,}417.84\ ft^3/s}$$

Station Values for the above flood Peak are:

$Q_{0.1} = 778\ ft^3/s$

$Q_{0.04} = 1070\ ft^3/s$

$Q_{0.02} = 1320\ ft^3/s$

$Q_{0.01} = 1610\ ft^3/s$

Ref: USGS TABLE PAPER 2214.

Project: Corp of Engrs - Waltham
Job No.: JC-151-II
Sheet No:
Subject: Goodnow Rd. Bridge
Computed By: C.A.A
Date: 4/21/93
Detail: Scour Analysis
Checked By:
Date:

Weighted Discharge for the flood Peak

For $Q_{0.1}$

$$Q_{t(w)} = \frac{(Q_{t(s)} \times N) + (Q_{t(r)} \times E)}{N + E}$$

Using U.S.G.S Table 3
Paper 2214

$N = 58$
$E = ?$ (Values from Table 5)

$$\therefore Q_{0.1} = \frac{(778 \times 58) + (675.41 \times 9)}{58 + 9}$$

$$= 764.22 \text{ cfs}$$

$$Q_{0.04} = \frac{(1070 \times 58) + (925.08 \times 9)}{58 + 9}$$

$$= \underline{\underline{1050.53 \text{ ft}^3/\text{s}}}$$

$$Q_{0.02} = \frac{(1320 \times 58) + 1149 \times 11}{58 + 11}$$

$$= \underline{\underline{1292.74 \text{ ft}^3/\text{s}}}$$

$$Q_{0.01} = \frac{(1610 \times 58) + 1417.84 \times 11}{58 + 11}$$

$$= \underline{\underline{1579.37 \text{ ft}^3/\text{s}}}$$

Area of Gage Site = 19.4 = A_g

Area of Ungage Site = 23.58 = A_u

$$\text{Ratio} = \frac{A_u}{A_g} = \frac{23.58}{19.4} = \underline{\underline{1.22}} < 1.4$$

O.K.

Weighted station Discharge Computed above can now be transferred to the site.

$$Q_{t(u)} = \left(\frac{A_u}{A_g}\right)^x Q_{t(g)}$$

$x = 0.7$ (Regional exponent of transfer given in the Scope of Service).

Although U.S.G.S provides for 0.75, we will use 0.7 as provided in the Scope.

$$Q_{0.1} = (1.22)^{0.7}(764.22) = \underline{878.36} \text{ cfs}$$

$$Q_{0.04} = (1.22)^{0.7}(1050.53) = \underline{1207.43 \text{ cfs}}$$

$$Q_{0.02} = (1.22)^{0.7}(1292.74) = \underline{1485.81 \text{ cfs}}$$

$$Q_{0.01} = (1.22)^{0.7}(1579.37) = \underline{1815.25 \text{ cfs}}$$

Using Log-Pearson method for Discharge frequencies as calculated.

10 yr = 833 cfs

25 yr = 1245 cfs

50 yr = 1540 cfs

100 yr = 1960 cfs

Weighted Discharge for the flood Peak at site

$$Q_{t(u)} = \left(\frac{A_u}{A_g}\right)^{0.7} Q_{t(g)}$$

$10\,yr = Q_{0.1} = \left(\frac{23.58}{19.40}\right)^{0.7}(833) = \underline{\underline{955\ cfs}}$

$25\,yr = Q_{0.04} = (1.22)^{0.7}(1245) = \underline{\underline{1431\ cfs}}$

$50\,yr = Q_{0.02} = (1.22)^{0.7}(1540) = \underline{\underline{1770\ cfs}}$

$100\,yr = Q_{0.01} = (1.22)^{0.7}(1960) = \underline{\underline{2253\ cfs}}$

APPENDIX B

Hydraulic Computations

B O S S   W S P R O (tm)

Version : 2.00
Serial Number : 0020200.200

Licensed to Hydraulic and Water Resources Engineers

PROGRAM ORIGIN :

Boss Wspro (tm) is an enhanced version of James O. Shearman's June 1988 Federal Highway Administration - U. S. Geological Survey WSPRO program for water surface profile computations.

DISCLAIMER :

Boss Wspro (tm) is a complex program which requires engineering expertise to use correctly. Boss Corporation assumes absolutely no responsibility for the correct use of this program. All results obtained should be carefully examined by an experienced professional engineer to determine if they are reasonable and accurate.

Although Boss Corporation has endeavored to make Boss Wspro error free, the program is not and cannot be certified as infallible. Therefore, Boss Corporation makes no warranty, either implicit or explicit, as to the correct performance or accuracy of this software.

In no event shall Boss Corporation be liable to anyone for special, collateral, incidental, or consequential damages in connection with or arising out of purchase or use of this software. The sole and exclusive liability to Boss Corporation, regardless of the form of action, shall not exceed the purchase price of this software.

PROJECT DESCRIPTION :

```
PROJECT TITLE  : BRIDGE SCOUR ANALYSIS
PROJECT NUMBER : JC-151-II
DESCRIPTION    : GOODNOW BRIDGE OVER PRIEST BROOK
ENGINEER       : C.A.A
DATE OF RUN    :  9/28/1993
TIME OF RUN    :  2:03 pm
```

```
T1
T2
T3
*
*      10, 25, 50 and 100 year flood profiles
*
J1              0.1       0.1        *         *         0
```

JOB PARAMETERS :

Elevation Stepping Increment (DELTAY, ft)	.1000
Allowable Elevation Tolerance (YTOL, ft)	.1000
Allowable Discharge Tolerance (QTOL, %)	.0200
Froude Test Value (FNTEST)	.8000
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

```
*
Q            955.0    1431.0    1455.0    1770.0    2253.0
WS          837.44    838.98    838.99    841.34    841.39
*
*
T3       MOST DOWN STREAM SECTION
```

PROCESSING CROSS-SECTION 00001 : MOST DOWN STREAM SECTION

INPUT CARD FILE :

```
XS   00001   1000.0         *       0.3       0.1       0.0
GR              0.0     841.1      10.0     841.0      31.0     840.7
GR             53.0     840.2     103.0     838.8     153.0     832.7
GR            162.0     831.2     171.0     830.7     178.0     831.5
GR            185.0     832.7     239.0     836.2     289.0     839.2
GR            321.0     841.1     370.0     841.3
N              0.11      0.04      0.11
SA            103.0     239.0
FL 0            *         *         *         *         *
*
T3       DOWNSTREAM SECTION
```

DATA SUMMARY FOR CROSS-SECTION 00001 :

Section Reference Distance (SRD, ft)	1000.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.00000
Expansion Coefficient (EK)	.30
Contraction Coefficient (CK)	.10

Computation Method GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	841.10	10.00	841.00	31.00	840.70
53.00	840.20	103.00	838.80	153.00	832.70
162.00	831.20	171.00	830.70	178.00	831.50
185.00	832.70	239.00	836.20	289.00	839.20
321.00	841.10	370.00	841.30		

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
103.00	.0400
239.00	.1100

PROCESSING CROSS-SECTION 00002 : DOWNSTREAM SECTION

INPUT CARD FILE :

```
XS   00002   1020.0        *      0.3      0.1    0.025
GR              0.0    844.3     10.0    844.2     30.0    842.9
GR             52.0    840.0    112.0    839.4    152.0    832.7
GR            161.0    830.5    170.0    830.2    177.0    830.6
GR            184.0    832.7    238.0    836.7    288.0    838.7
GR            338.0    839.4    380.0    839.6    400.0    840.8
N              0.11     0.04     0.11
SA            112.0    238.0
FL 0              *        *        *        *        *
*
T3        EXIT SECTION
```

DATA SUMMARY FOR CROSS-SECTION 00002 :

Section Reference Distance (SRD, ft)	1020.00
Error Code (ERR)	0

Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.02500
Expansion Coefficient (EK)	.30
Contraction Coefficient (CK)	.10
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	844.30	10.00	844.20	30.00	842.90
52.00	840.00	112.00	839.40	152.00	832.70
161.00	830.50	170.00	830.20	177.00	830.60
184.00	832.70	238.00	836.70	288.00	838.70
338.00	839.40	380.00	839.60	400.00	840.80

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
112.00	.0400
238.00	.1100

PROCESSING CROSS-SECTION 00003 : EXIT SECTION

INPUT CARD FILE :

```
XS   00003    1028.0         *       0.3       0.1     0.065
GR               0.0     846.3       5.0     846.2      55.0     840.5
GR             105.0     841.3     151.0     838.1     158.0     833.2
GR             165.0     829.8     172.0     828.9     180.0     830.1
GR             187.0     833.2     240.0     837.7     290.0     839.7
GR             340.0     843.3     372.0     843.5
N               0.11      0.04      0.11
SA             151.0     240.0
FL 0               *         *         *         *         *
*
T3        BRIDGE SECTION
```

DATA SUMMARY FOR CROSS-SECTION 00003 :

Section Reference Distance (SRD, ft)	1028.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.06500
Expansion Coefficient (EK)	.30
Contraction Coefficient (CK)	.10
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	846.30	5.00	846.20	55.00	840.50
105.00	841.30	151.00	838.10	158.00	833.20
165.00	829.80	172.00	828.90	180.00	830.10
187.00	833.20	240.00	837.70	290.00	839.70
340.00	843.30	372.00	843.50		

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
151.00	.0400
240.00	.1100

PROCESSING CROSS-SECTION 00004 : BRIDGE SECTION

INPUT CARD FILE :

```
XS   00004   1044.0       *      0.5      0.3      0.0
GR             0.0    845.2      9.0    845.0     59.0    843.6
GR           109.0    843.2    143.0    836.1    156.0    833.1
GR           162.0    831.3    172.0    831.2    182.0    831.3
GR           188.0    833.1    202.0    835.2    252.0    841.5
GR           302.0    841.9    352.0    842.6    384.0    842.9
N             0.11     0.04     0.11
SA           143.0    202.0
FL 0             *        *        *        *        *
*
```

DATA SUMMARY FOR CROSS-SECTION 00004 :

Section Reference Distance (SRD, ft)	1044.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.00000
Expansion Coefficient (EK)	.50
Contraction Coefficient (CK)	.30
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	845.20	9.00	845.00	59.00	843.60
109.00	843.20	143.00	836.10	156.00	833.10
162.00	831.30	172.00	831.20	182.00	831.30
188.00	833.10	202.00	835.20	252.00	841.50
302.00	841.90	352.00	842.60	384.00	842.90

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
143.00	.0400
202.00	.1100

PROCESSING CROSS-SECTION 00005 : BRIDGE SECTION

INPUT CARD FILE :

```
BR  00005   1044.0    841.5      7.0      0.5      0.3        *
GR           163.8    841.5    163.8    831.2    180.2    831.2
GR           180.2    841.5    163.8    841.5
AB               *        *    834.2    834.2
CD               2     22.5      3.0    843.6        *        *        *
N            0.017    0.017
SA           180.2
*
```

DATA SUMMARY FOR CROSS-SECTION 00005 :

Section Reference Distance (SRD, ft)	1044.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	7.00
Valley Slope or Grade (VSLOPE, ft/ft)	.00000
Expansion Coefficient (EK)	.50
Contraction Coefficient (CK)	.30
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

BRIDGE OPENING GEOMETRY (X-Y coordinate pairs) :

Horiz. Station X(I) (ft)	Opening Elevation Y(I) (ft MSL)	Horiz. Station X(I+1) (ft)	Opening Elevation Y(I+1) (ft MSL)	Horiz. Station X(I+2) (ft)	Opening Elevation Y(I+2) (ft MSL)
163.80	841.50	163.80	831.20	180.20	831.20
180.20	841.50	163.80	841.50		

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.0170
180.20	.0170

BRIDGE DESCRIPTION :

Bridge Opening Type (BRTYPE)	2
Bridge Deck Width (BRWDTH, ft)	22.50
Bridge Opening Low Chord Elev (LSEL, ft MSL)	841.50
Bridge Discharge Coefficient (USERCD)	**********
Bridge Embankment Side Slope (EMBSS)	1 : 3.000
Top of Embankment Elevation (EMBELV, ft MSL)	843.60
Left Abutment Toe Elevation (YABLT, ft MSL)	834.20
Right Abutment Toe Elevation (YABRT, ft MSL)	834.20

PROCESSING CROSS-SECTION 00006 : BRIDGE SECTION

INPUT CARD FILE :

```
XR   00006    1070.0      20.0        2          *         7.0
GR              0.0      845.2       9.0      845.0       59.0      843.6
GR            109.0      843.2     143.0      843.2      158.0      843.5
GR            165.0      843.6     172.0      843.5      179.0      842.9
GR            187.0      842.4     202.0      841.9      252.0      841.5
GR            302.0      841.9     352.0      842.6      384.0      842.9
*
T3        APPROACH SECTION
```

STATUS: No roughness data input, will propagate from previous cross-section.

DATA SUMMARY FOR CROSS-SECTION 00006 :

Section Reference Distance (SRD, ft)	1070.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	7.00
Valley Slope or Grade (VSLOPE, ft/ft)	.00000
Expansion Coefficient (EK)	.50
Contraction Coefficient (CK)	.30

Computation Method GEOMETRIC MEAN OF CONVEYANCES

ROAD GEOMETRY (X-Y coordinate pairs) :

Horiz. Station X(I) (ft)	Opening Elevation Y(I) (ft MSL)	Horiz. Station X(I+1) (ft)	Opening Elevation Y(I+1) (ft MSL)	Horiz. Station X(I+2) (ft)	Opening Elevation Y(I+2) (ft MSL)
.00	845.20	9.00	845.00	59.00	843.60
109.00	843.20	143.00	843.20	158.00	843.50
165.00	843.60	172.00	843.50	179.00	842.90
187.00	842.40	202.00	841.90	252.00	841.50
302.00	841.90	352.00	842.60	384.00	842.90

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
143.00	.0400
202.00	.1100

ROAD GRADE DESCRIPTION :

Road Surface Material (IPAVE)	GRAVEL
Embankment Top Width (RDWID, m)	20.00
Weir Flow Coefficient (USERCF)	**********

PROCESSING CROSS-SECTION 00007 : APPROACH SECTION

INPUT CARD FILE :

```
AS   00007   1080.0         *       0.3       0.1     0.037
GR              0.0     851.1      33.0     847.2      55.0     841.9
GR            115.0     834.8     161.0     833.4     167.0     832.9
GR            173.0     832.5     180.0     832.8     188.0     833.4
GR            238.0     837.7     288.0     841.0     321.0     842.8
GR            370.0     842.9
N              0.11      0.04      0.11
SA            115.0     238.0
FL 0              *         *         *         *         *
*
T3        UPSTREAM SECTION
```

DATA SUMMARY FOR CROSS-SECTION 00007 :

Section Reference Distance (SRD, ft)	1080.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.03700
Expansion Coefficient (EK)	.30
Contraction Coefficient (CK)	.10
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	851.10	33.00	847.20	55.00	841.90
115.00	834.80	161.00	833.40	167.00	832.90
173.00	832.50	180.00	832.80	188.00	833.40
238.00	837.70	288.00	841.00	321.00	842.80
370.00	842.90				

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
115.00	.0400
238.00	.1100

PROCESSING CROSS-SECTION 00008 : UPSTREAM SECTION

INPUT CARD FILE :

```
XS   00008    1119.0         *       0.3       0.1      0.13
GR               0.0     847.9      28.0     845.2      50.0     843.4
GR             100.0     834.2     171.5     834.4     171.5     833.4
GR             178.0     830.0     184.0     829.9     191.0     830.1
GR             197.0     833.4     250.0     836.8     300.0     840.0
GR             333.0     841.9     382.0     842.3     415.0     843.3
N               0.11      0.04      0.11
SA             100.0     250.0
FL 0               *         *         *         *         *
*
EX                 0         0         0         0         0
```

DATA SUMMARY FOR CROSS-SECTION 00008 :

Section Reference Distance (SRD, ft)	1119.00
Error Code (ERR)	0
Cross-Section Skew (SKEW, degrees)	.00
Valley Slope or Grade (VSLOPE, ft/ft)	.13000
Expansion Coefficient (EK)	.30
Contraction Coefficient (CK)	.10
Computation Method	GEOMETRIC MEAN OF CONVEYANCES

CROSS-SECTION GEOMETRY (X-Y coordinate pairs) :

Ground Station X(I) (ft)	Ground Elevation Y(I) (ft MSL)	Ground Station X(I+1) (ft)	Ground Elevation Y(I+1) (ft MSL)	Ground Station X(I+2) (ft)	Ground Elevation Y(I+2) (ft MSL)
.00	847.90	28.00	845.20	50.00	843.40
100.00	834.20	171.50	834.40	171.50	833.40
178.00	830.00	184.00	829.90	191.00	830.10
197.00	833.40	250.00	836.80	300.00	840.00
333.00	841.90	382.00	842.30	415.00	843.30

CROSS-SECTION ROUGHNESS DESCRIPTION :

Horiz. Break-Point Station (ft)	Subarea Manning n
*********	.1100
100.00	.0400
250.00	.1100

BEGINNING PROFILE CALCULATIONS :

PROFILE NUMBER 1 :

Cross Section ID Code XSID	Flow Length FLEN (ft)	Flow Area AREA (sq ft)	Left Edge of Water LEW (ft)	Vel. Head Correct. Factor ALPH	Friction Loss HF (ft)	Energy Gradeline Elevation EGL (ft MSL)
Section Reference Distance SRD (ft)	Reference Distance Increment SRDL (ft)	Convyance K	Flow Top Width REW-LEW (ft)	Froude Number FR#	Other Losses HO (ft)	Velocity Head VHD (ft)
Cross Section Type CODE	Discharge Q (cfs)	Critical Flow Elevation CRWS (ft MSL)	Right Edge of Water REW (ft)	Flow Velocity VEL (ft/s)	Energy Balance Error ERR (ft)	Water Surface Elevation WSEL (ft MSL)
00001	*********	455.9	114.15	1.048	*********	837.51
1000.00	*********	38392	145.52	.214	*********	.07
STANDARD	955	834.44	259.67	2.095	*********	837.44
00002	20.00	421.5	124.00	1.026	.013	837.47
1020.00	20.00	36456	131.25	.226	.003	.08
STANDARD	955	*********	255.25	2.266	-.056	837.39
00003	8.00	312.5	152.09	1.000	.007	837.49
1028.00	8.00	27362	83.67	.279	.019	.15
STANDARD	955	*********	235.76	3.056	-.013	837.34
00004	16.00	281.5	137.30	1.129	.020	837.49
1044.00	16.00	26141	81.29	.342	.028	.20
FULVALLEY	955	*********	218.59	3.392	-.042	837.29
00007	36.00	400.4	92.69	1.111	.042	837.54
1080.00	36.00	29764	142.29	.264	.010	.10
APPROACH	955	*********	234.98	2.385	-.006	837.44

STATUS: The above results reflect NORMAL (unconstricted) flow.

STATUS: Results reflecting the constricted flow follow.

00005	16.00	86.4	163.80	1.253	.045	838.89
1044.00	16.00	16478	16.40	.947	1.332	2.38
BRIDGE	955	835.95	180.20	11.058	-.029	836.51

Bridge Opening Type (TYPE)	2.
Column Type Code (PPCD)	**********
Flow Class (FLOW)	1.
Bridge Opening Discharge Coefficient (C)	.893
Ratio of Pier Area/Gross Bridge Area (P/A)	**********
Bridge Low Chord Elevation (LSEL, ft MSL)	841.50
Bridge Length (BLEN, ft)	**********
Left Abutment Toe Station (XLAB, ft)	**********
Right Abutment Toe Station (XRAB, ft)	**********

STATUS: Roadway embankment is not overtopped.

Error Code (ERRFLG)	NONE
Cross-Section ID Code (SECID)	00006
Cross-Section Type (XSCODE)	ROADGRADE
Cross-Section Reference Distance (SRD, ft)	1070.00

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00007	17.98	656.1	79.21	1.223	.024	839.08
1080.00	13.50	60203	179.02	.148	.191	.04
APPROACH	955	835.29	258.23	1.456	.080	839.04

Geometric Contraction Ratio (M(G))	.885
Flow Contraction Ratio (M(K))	.798
Kq-Section Conveyance (KQ)	11788.
Kq-Section Left Limit Station (XLKQ, ft)	157.02
Kq-Section Right Limit Station (XRKQ, ft)	173.42
Min Roadgrade Elevation Allowed w/o Overtopping (OTEL, ft MSL)	839.03

STATUS: End of bridge computations.

00008	39.00	848.3	73.99	1.192	.007	839.01
1119.00	39.00	82498	210.15	.108	.002	.02
STANDARD	955	*********	284.14	1.126	-.076	838.99

PROFILE NUMBER 2 :

00001	*********	710.0	96.57	1.155	*********	839.05
1000.00	*********	68649	188.76	.197	*********	.07
STANDARD	1431	835.07	285.33	2.016	*********	838.98

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00002	20.00	661.5	114.81	1.177	.009	839.02
1020.00	20.00	64287	189.62	.221	.004	.09
STANDARD	1431	*********	304.43	2.163	-.050	838.93
00003	8.00	470.2	139.79	1.086	.005	839.04
1028.00	8.00	48105	129.71	.294	.021	.16
STANDARD	1431	*********	269.50	3.043	-.006	838.88
00004	16.00	421.8	129.93	1.312	.016	839.06
1044.00	16.00	43913	100.88	.335	.039	.23
FULVALLEY	1431	*********	230.81	3.393	-.026	838.83
00007	36.00	646.2	79.68	1.218	.028	839.07
1080.00	36.00	58968	177.72	.226	.014	.09
APPROACH	1431	*********	257.39	2.214	-.035	838.98

STATUS: The above results reflect NORMAL (unconstricted) flow.

STATUS: Results reflecting the constricted flow follow.

00005	16.00	107.8	163.80	1.225	.033	841.18
1044.00	16.00	22418	16.40	1.006	2.094	3.35
BRIDGE	1431	837.46	180.20	13.269	-.015	837.83

Bridge Opening Type (TYPE)	2.
Column Type Code (PPCD)	**********
Flow Class (FLOW)	1.
Bridge Opening Discharge Coefficient (C)	.904
Ratio of Pier Area/Gross Bridge Area (P/A)	**********
Bridge Low Chord Elevation (LSEL, ft MSL)	841.50
Bridge Length (BLEN, ft)	**********
Left Abutment Toe Station (XLAB, ft)	**********
Right Abutment Toe Station (XRAB, ft)	**********

STATUS: Roadway embankment is not overtopped.

Error Code (ERRFLG)	NONE
Cross-Section ID Code (SECID)	00006
Cross-Section Type (XSCODE)	ROADGRADE
Cross-Section Reference Distance (SRD, ft)	1070.00

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00007	18.87	1129.4	59.81	1.472	.015	841.37
1080.00	13.50	121858	234.26	.123	.189	.04
APPROACH	1431	835.74	294.07	1.267	.053	841.33

Geometric Contraction Ratio (M(G))	.908
Flow Contraction Ratio (M(K))	.827
Kq-Section Conveyance (KQ)	20829.
Kq-Section Left Limit Station (XLKQ, ft)	158.47
Kq-Section Right Limit Station (XRKQ, ft)	174.87
Min Roadgrade Elevation Allowed w/o Overtopping (OTEL, ft MSL)	841.33

STATUS: End of bridge computations.

00008	39.00	1387.7	61.52	1.387	.004	841.30
1119.00	39.00	159040	260.73	.093	.001	.02
STANDARD	1431	*********	322.25	1.031	-.069	841.28

PROFILE NUMBER 3 :

00001	*********	711.8	96.21	1.156	*********	839.07
1000.00	*********	68898	189.29	.200	*********	.08
STANDARD	1455	835.07	285.50	2.044	*********	838.99
00002	20.00	663.4	114.75	1.178	.010	839.03
1020.00	20.00	64493	190.40	.225	.004	.09
STANDARD	1455	*********	305.14	2.193	-.050	838.94
00003	8.00	471.5	139.64	1.087	.005	839.05
1028.00	8.00	48268	130.11	.298	.022	.16
STANDARD	1455	*********	269.75	3.086	-.004	838.89
00004	16.00	422.8	129.88	1.313	.016	839.08
1044.00	16.00	44043	101.01	.340	.040	.24
FULVALLEY	1455	*********	230.89	3.441	-.026	838.84
00007	36.00	648.0	79.59	1.219	.029	839.09
1080.00	36.00	59191	177.95	.229	.015	.10
APPROACH	1455	*********	257.55	2.245	-.040	838.99

XSID	FLEN	AREA	LEW	ALPH	HF	EGL
SRD	SRDL	K	REW-LEW	FR#	HO	VHD
CODE	Q	CRWS	REW	VEL	ERR	WSEL

STATUS: The above results reflect NORMAL (unconstricted) flow.

STATUS: Results reflecting the constricted flow follow.

00005	16.00	107.4	163.80	1.225	.033	841.29
1044.00	16.00	22278	16.40	1.030	2.193	3.50
BRIDGE	1455	837.46	180.20	13.553	-.016	837.80

Bridge Opening Type (TYPE)	2.
Column Type Code (PPCD)	**********
Flow Class (FLOW)	1.
Bridge Opening Discharge Coefficient (C)	.904
Ratio of Pier Area/Gross Bridge Area (P/A)	**********
Bridge Low Chord Elevation (LSEL, ft MSL)	841.50
Bridge Length (BLEN, ft)	**********
Left Abutment Toe Station (XLAB, ft)	**********
Right Abutment Toe Station (XRAB, ft)	**********

STATUS: Roadway embankment is not overtopped.

Error Code (ERRFLG)	NONE
Cross-Section ID Code (SECID)	00006
Cross-Section Type (XSCODE)	ROADGRADE
Cross-Section Reference Distance (SRD, ft)	1070.00

00007	18.88	1157.8	58.79	1.486	.015	841.49
1080.00	13.50	125650	237.48	.122	.197	.04
APPROACH	1455	835.74	296.28	1.257	.059	841.45

Geometric Contraction Ratio (M(G))	.908
Flow Contraction Ratio (M(K))	.828
Kq-Section Conveyance (KQ)	21313.
Kq-Section Left Limit Station (XLKQ, ft)	158.50
Kq-Section Right Limit Station (XRKQ, ft)	174.90
Min Roadgrade Elevation Allowed w/o Overtopping (OTEL, ft MSL)	841.45

STATUS: End of bridge computations.

00008	39.00	1419.3	60.86	1.398	.004	841.42
1119.00	39.00	163690	263.48	.092	.001	.02
STANDARD	1455	*********	324.34	1.025	-.069	841.40

PROFILE NUMBER 4 :

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00001 1000.00 STANDARD	********* ********* 1770	1317.7 138797 835.37	.00 370.00 370.00	1.618 .160 1.343	********* ********* *********	841.39 .05 841.34

STATUS: (140) End of cross-section extended vertically.

Cross-Section ID code (SECID)	00002
Final Computed Water Surface Elevation (WSEL, ft MSL)	841.29
Left-Most Ground Elevation (YLT, ft MSL)	844.30
Right-Most Ground Elevation (YRT, ft MSL)	840.80

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00002 1020.00 STANDARD	20.00 20.00 1770	1385.0 133495 *********	42.21 357.79 400.00	1.848 .156 1.278	.003 .000 -.052	841.34 .05 841.29
00003 1028.00 STANDARD	8.00 8.00 1770	892.3 95135 *********	48.51 262.88 311.39	1.603 .238 1.984	.002 .015 -.016	841.34 .10 841.24
00004 1044.00 FULVALLEY	16.00 16.00 1770	695.3 79759 *********	118.63 130.92 249.54	1.621 .248 2.546	.007 .033 -.024	841.35 .16 841.19

WARNING: (135) Conveyance ratio outside of recommended conveyance ratio limits.

Cross-Section ID Code (SECID)	00007
Computed Conveyance Ratio (KRATIO)	1.492

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00007 1080.00 APPROACH	36.00 36.00 1770	1108.2 119032 *********	60.58 231.82 292.40	1.461 .156 1.597	.012 .011 -.078	841.30 .06 841.24

STATUS: (215) Flow class 1 solution indicates possible road overflow.

Bridge Approach Water Surface Elevation (WS1, ft MSL)	843.22
Spur Dike (if any) Water Surface Elevation (WSSD, ft MSL)	.00
Bridge Opening Water Surface Elevation (WS3, ft MSL)	840.62
Minimum Road Elevation (RGMIN, ft MSL)	841.50

STATUS: (260) Attempting flow class 4 solution.

STATUS: (220) Flow class 1 (or 4) solution indicates possible pressure flow.

Bridge Tailwater Elevation (WS3, ft MSL)	841.19
Bridge Upstream Water Surface Elevation (WSIU, ft MSL)	842.63
Bridge Approach Water Surface Elevation (WS1, ft MSL)	842.64
Bridge low-chord elevation (LSEL, ft MSL)	841.50

STATUS: (245) Attempting flow class 2 (or 5) solution.

XSID	FLEN	AREA	LEW	ALPH	HF	EGL
SRD	SRDL	K	REW-LEW	FR#	HO	VHD
CODE	Q	CRWS	REW	VEL	ERR	WSEL

STATUS: The above results reflect NORMAL (unconstricted) flow.

STATUS: Results reflecting the constricted flow follow.

00005	*********	167.7	163.80	1.000	*********	842.51
1044.00	16.00	31557	16.40	.444	*********	1.01
BRIDGE	1349	837.16	180.20	8.047	*********	841.50

Bridge Opening Type (TYPE)	2.
Column Type Code (PPCD)	**********
Flow Class (FLOW)	5.
Bridge Opening Discharge Coefficient (C)	.396
Ratio of Pier Area/Gross Bridge Area (P/A)	**********
Bridge Low Chord Elevation (LSEL, ft MSL)	841.50
Bridge Length (BLEN, ft)	**********
Left Abutment Toe Station (XLAB, ft)	**********
Right Abutment Toe Station (XRAB, ft)	**********

Cross-Section ID Code	00006
Cross-Section Type (CODE)	ROADGRADE
Section Reference Distance (SRD, ft)	1070.00
Flow Length (FLEN, ft)	16.00
Friction Loss (HF, ft)	.002
Velocity Head (VHD, ft)	.036
Energy Gradeline Elevation (EGL, ft MSL)	842.81
Energy Balance Error (ERR, ft)	-.01
Discharge (Q, cfs)	409.
Computed Water Surface Elevation (WSEL, ft MSL)	842.59

Overflow Results for Left Side of Roadway

Discharge (Q, cfs)	0.
Road Overflow Weir Length (WLEN, ft)	91.33
Left Edge of Water (LEW, ft)	68.90
Right Edge of Water (REW, ft)	172.00
Maximum Weir Flow Depth (DMAX, ft)	.32
Average Weir Flow Depth (DAVG, ft)	.22
Estimated Maximum Road Overflow Velocity (VMAX, ft/s)	3.238
Average Road Overflow Velocity (VAVG, ft/s)	3.238
Average Total Head for Weir Flow (HAVG, ft)	.62
Average Weir Coefficient (CAVG)	2.740

Overflow Results for Right Side of Roadway

Discharge (Q, cfs)	409.
Road Overflow Weir Length (WLEN, ft)	166.16
Left Edge of Water (LEW, ft)	183.95
Right Edge of Water (REW, ft)	351.35
Maximum Weir Flow Depth (DMAX, ft)	1.09
Average Weir Flow Depth (DAVG, ft)	.68
Estimated Maximum Road Overflow Velocity (VMAX, ft/s)	4.137
Average Road Overflow Velocity (VAVG, ft/s)	3.649
Average Total Head for Weir Flow (HAVG, ft)	.89
Average Weir Coefficient (CAVG)	2.918

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00007	20.24	1494.0	51.37	1.638	.009	842.81
1080.00	13.50	171412	269.17	.113	.043	.04
APPROACH	1770	836.03	320.54	1.185	-.006	842.78

Geometric Contraction Ratio (M(G))	**********
Flow Contraction Ratio (M(K))	**********
Kq-Section Conveyance (KQ)	**********
Kq-Section Left Limit Station (XLKQ, ft)	**********
Kq-Section Right Limit Station (XRKQ, ft)	**********
Min Roadgrade Elevation Allowed w/o Overtopping (OTEL, ft MSL)	**********

STATUS: End of bridge computations.

00008	39.00	1815.7	53.67	1.583	.003	842.75
1119.00	39.00	218174	342.36	.094	.001	.02
STANDARD	1770	*********	396.03	.975	-.067	842.73

PROFILE NUMBER 5 :

XSID SRD CODE	FLEN SRDL Q	AREA K CRWS	LEW REW-LEW REW	ALPH FR# VEL	HF HO ERR	EGL VHD WSEL
00001	*********	1336.2	.00	1.632	*********	841.46
1000.00	*********	140701	370.00	.200	*********	.07
STANDARD	2253	835.89	370.00	1.686	*********	841.39

STATUS: (140) End of cross-section extended vertically.

Cross-Section ID code (SECID)	00002
Final Computed Water Surface Elevation (WSEL, ft MSL)	841.34
Left-Most Ground Elevation (YLT, ft MSL)	844.30
Right-Most Ground Elevation (YRT, ft MSL)	840.80

00002	20.00	1402.9	41.83	1.858	.005	841.41
1020.00	20.00	135356	358.17	.195	.001	.07
STANDARD	2253	*********	400.00	1.606	-.054	841.34
00003	8.00	905.4	48.07	1.621	.003	841.45
1028.00	8.00	96343	264.01	.301	.024	.16
STANDARD	2253	*********	312.08	2.489	.004	841.29
00004	16.00	701.9	118.39	1.628	.010	841.50
1044.00	16.00	80634	131.55	.313	.052	.26
FULVALLEY	2253	*********	249.94	3.210	-.008	841.24

WARNING: (135) Conveyance ratio outside of recommended conveyance ratio limits.

Cross-Section ID Code (SECID)	00007
Computed Conveyance Ratio (KRATIO)	1.534

00007	36.00	1143.3	59.31	1.479	.018	841.48
1080.00	36.00	123709	235.84	.192	.017	.09
APPROACH	2253	*********	295.15	1.971	-.057	841.39

STATUS: (215) Flow class 1 solution indicates possible road overflow.

Bridge Approach Water Surface Elevation (WS1, ft MSL)	844.84
Spur Dike (if any) Water Surface Elevation (WSSD, ft MSL)	.00
Bridge Opening Water Surface Elevation (WS3, ft MSL)	840.24
Minimum Road Elevation (RGMIN, ft MSL)	841.50

STATUS: (260) Attempting flow class 4 solution.

```
STATUS: (220) Flow class 1 (or 4) solution indicates possible pressure
        flow.

        Bridge Tailwater Elevation (WS3, ft MSL)                     841.41
        Bridge Upstream Water Surface Elevation (WSIU, ft MSL)       843.16
        Bridge Approach Water Surface Elevation (WS1, ft MSL)        843.17
        Bridge low-chord elevation (LSEL, ft MSL)                    841.50


STATUS: (245) Attempting flow class 2 (or 5) solution.


WARNING: (265) Road overflow appears excessive.

         Road Overflow (QRD, cfs)                                    742.01
         Maximum Road Overflow (QRDMAX, cfs)                         702.10
         Road Overflow Ratio (QRD/QRDMAX)                              1.06


XSID      FLEN      AREA      LEW       ALPH      HF        EGL
SRD       SRDL      K         REW-LEW   FR#       HO        VHD
CODE      Q         CRWS      REW       VEL       ERR       WSEL
--------- --------- --------- --------- --------- --------- ---------

STATUS: The above results reflect NORMAL (unconstricted) flow.

STATUS: Results reflecting the constricted flow follow.

    00005 *********     167.7    163.80     1.000 *********    842.75
  1044.00     16.00     31557     16.40      .495 *********      1.25
   BRIDGE      1505    837.66    180.20     8.975 *********    841.50


Bridge Opening Type (TYPE)                                             2.
Column Type Code (PPCD)                                        **********
Flow Class (FLOW)                                                      5.
Bridge Opening Discharge Coefficient (C)                             .429
Ratio of Pier Area/Gross Bridge Area (P/A)                     **********
Bridge Low Chord Elevation (LSEL, ft MSL)                          841.50
Bridge Length (BLEN, ft)                                       **********
Left Abutment Toe Station (XLAB, ft)                           **********
Right Abutment Toe Station (XRAB, ft)                          **********
```

Cross-Section ID Code	00006
Cross-Section Type (CODE)	ROADGRADE
Section Reference Distance (SRD, ft)	1070.00
Flow Length (FLEN, ft)	16.00
Friction Loss (HF, ft)	.002
Velocity Head (VHD, ft)	.053
Energy Gradeline Elevation (EGL, ft MSL)	843.20
Energy Balance Error (ERR, ft)	.00
Discharge (Q, cfs)	742.
Computed Water Surface Elevation (WSEL, ft MSL)	842.92

Overflow Results for Left Side of Roadway

Discharge (Q, cfs)	0.
Road Overflow Weir Length (WLEN, ft)	94.74
Left Edge of Water (LEW, ft)	67.28
Right Edge of Water (REW, ft)	172.00
Maximum Weir Flow Depth (DMAX, ft)	.33
Average Weir Flow Depth (DAVG, ft)	.22
Estimated Maximum Road Overflow Velocity (VMAX, ft/s)	3.264
Average Road Overflow Velocity (VAVG, ft/s)	3.264
Average Total Head for Weir Flow (HAVG, ft)	.63
Average Weir Coefficient (CAVG)	2.745

Overflow Results for Right Side of Roadway

Discharge (Q, cfs)	742.
Road Overflow Weir Length (WLEN, ft)	203.67
Left Edge of Water (LEW, ft)	178.80
Right Edge of Water (REW, ft)	384.00
Maximum Weir Flow Depth (DMAX, ft)	1.42
Average Weir Flow Depth (DAVG, ft)	.85
Estimated Maximum Road Overflow Velocity (VMAX, ft/s)	4.829
Average Road Overflow Velocity (VAVG, ft/s)	4.296
Average Total Head for Weir Flow (HAVG, ft)	1.13
Average Weir Coefficient (CAVG)	3.027

STATUS: (140) End of cross-section extended vertically.

Cross-Section ID code (SECID)	00007
Final Computed Water Surface Elevation (WSEL, m MSL)	843.15
Left-Most Ground Elevation (YLT, m MSL)	851.10
Right-Most Ground Elevation (YRT, m MSL)	842.90

APPENDIX C

Scour Computations Using FHWA HY – 9

GOODNOW ROAD BRIDGE SCOUR COMPUTATION USING FHWA HY-9

****

CONTRACTION SCOUR

CASE 2 The normal river channel width becoming narrower either because of the bridge itself or the bridge site being located at a narrower reach.

$$\frac{y_2}{y_1}=\left(\frac{Q_{mc2}}{Q_{mc1}}\right)^{\frac{6}{7}}\left(\frac{W_{c1}}{W_{c2}}\right)^{k1}\left(\frac{n2}{n1}\right)^{k2}\ldots\ldots\ldots\ldots\ldots(1)$$

$$y_{cs} = y_2 - y_1 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

1	flow depth @ approach	y_1	=	8.52 ft
2	width @ approach	W_{c1}	=	25 ft
3	width @ constriction	W_{c2}	=	16.4 ft
4	contracted flow	Q_{mc2}	=	1455 cfs
5	main channel flow @ approach	Q_{mc1}	=	684 cfs
6	shear velocity/fall velocity	V_{*c}/w	=	0.35
7	Manning n ratio (contracted/approach)		=	1.0
8	coefficient.	k_1	=	0.59
9	coefficient	k_2	=	0.066

RESULTS:

FLOW DEPTH AT BRIDGE OPENING	y_2 = 20.8 ft
CONTRACTION SCOUR DEPTH	y_{cs} = 12.3 ft

****

ABUTMENT SCOUR

ABUTMENT SET AT THE EDGE OF CHANNEL

$$\frac{Q_0}{q_{mc}y_0}=2.75\frac{y_{1s}}{y_0}\left[\left(\frac{y_{1s}}{4.1y_0}+1\right)^{\frac{7}{6}}-1\right]\ldots\ldots\ldots\ldots(3)$$

LEFT ABUTMENT:

1	inclination angle @ abutment	theta	=	83 deg
2	main channel flow @ approach	Q_c	=	684 cfs
3	overbank flow @ approach	Q_o	=	771 cfs
4	overbank depth @ approach	y_o	=	8.0 ft
5	main channel depth @ approach	y_1	=	8.52 ft
6	width of main channel	W	=	25 ft
7	unit discharge in main channel	q_{mc}	=	Q_c/W

RESULT:

ABUTMENT SCOUR DEPTH $y_{ls} = 15.8$ ft

RIGHT ABUTMENT:

1	inclination angle @ abutment	theta	=	97 deg
2	main channel flow @ approach	Q_c	=	684 cfs
3	overbank flow @ approach	Q_o	=	771 cgs
4	overbank depth @ approach	y_o	=	8.0 ft
5	main channel depth @ approach	y_1	=	8.52 ft
6	width of main channel	W	=	25 ft

RESULT:

ABUTMENT SCOUR DEPTH $y_{ls} = 16.6$ ft